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From the systems point of view, the objectives of higher education cannot be defined apart from the economic and social context in which the university operates. The report presents the results of a 4-year research project during which a mathematical model was developed to describe the way in which the university, as part of a socioeconomic system, utilizes its resources in production. The model, designed to aid university administrators in the overall allocation of resources, consists of sets of equations that describe the relationship of resources to production and, based on these, the associated unit costs of production. Resources (input) are described as personnel, space, and equipment, and products (output) as developed manpower, research, and public or technical services. The model does not tell the decision maker how to create a more effective educational institution, but provides him with a tool for evaluating the changes in the types of resources --or the potential economic gain-- which could result from proposed changes in the design of the institution. The report contains a brief non-technical review and a detailed technical description of the model, and discussion on and examples of how to use it in administration. Documented descriptions of data processing and simulation programs are also included, as well as a bibliography and auxiliary reports that were developed during the life of the project. (WM)

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Final Report
Project C-518
National Science Foundation
Washington, D. C.

A SYSTEMS MODEL FOR MANAGEMENT, PLANNING, AND RESOURCE ALLOCATION IN INSTITUTIONS OF HIGHER EDUCATION

U.S. DEPARTMENT OF HEALTH, EDUCATION & WELFARE
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HE 000 503

Division of Engineering Research
MICHIGAN STATE UNIVERSITY
East Lansing, Michigan

Final Report
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A SYSTEMS MODEL FOR MANAGEMENT, PLANNING, AND RESOURCE ALLOCATION IN INSTITUTIONS OF HIGHER EDUCATION

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September 30, 1968

PREFACE

This report presents the results of research and development carried out under National Science Foundation contracts C-396 and C-518, "Systems Approach to Higher Education," which extended over the period October 25, 1964, to September 30, 1968.

The objective of the development is to structure a mathematical model of an educational institution that will provide the "logic" of information processing programs to aid university administrators in the overall allocation of resources. The resources of the university are described in terms of measureable quantities of personnel, space, and equipment and the associated budget required to obtain them at the price levels imposed by the economic environment.

In pursuit of this objective, the university is viewed as a multivariable dynamic process, with manpower and physical facilities as input and with developed manpower, community service, and research as output. The patterns by which the inputs are used in the development of the outputs are identified and included as parameters in the model. In the process of identifying these parameters, the university is structured as a set of interacting sectors sufficiently detailed to give an accounting of the resources required in the various areas of operation. Thus, the model itself identifies a functional structure and within this functional structure establishes an accounting system which delineates both the quantity and the unit cost of the inputs and outputs associated with each sector of the university.

A change in operating policies, resource allocation, or management policy can be extrapolated into the future as a solution to the mathematical model of the system in the face of a change in parameters and/or input and output variables. Thus, the model is said to provide the capability for simulating and exploring the consequences of changes in various operating and managerial policies.

The model developed in this report identifies the structure involved in the educational process as it exists at any particular point in time at a given institution. It considers only the flow of resources and manpower and their associated unit values at particular points in time. It is not concerned with quality of education or the objectives of education as such. The model simply presents a picture of how the resources are used within the framework of the design of any given educational institution. Changes in the design of an educational institution in pursuit of a more efficient and effective "educational machine" are injected into the model by change in production functions and allocation policies. The model, therefore, does not tell the decision maker how to create a more effective educational institution. Rather, it provides him with a tool for evaluating the changes in the types of resources or the potential economic gain which would result from proposed changes in the design of the institution.

From the systems point of view, it is virtually impossible to define the objectives of higher education apart from the economic and social context in which the institution is expected to operate--the educational institution is but one part of an extensive socio-economic system. Its design must be dictated by the performance to be achieved in the larger system in which it functions. Thus, the logical approach to questions relating to manpower needs on the part of society and the effects that the demand for educational resources have on the economy can best be answered by simulating the effects of appropriate change in a model which characterizes the socio-economic process in which the educational sector is embedded. Seeing the projected results of any given change over time, the decision maker is in a position to debate the desirability of the projected change. A preliminary sketch of how the model of a university presented in this report might be used in such a context is described in Part 1 of this report.

The report is organized into six major parts. Sections within each part are identified by the part number followed by a colon and then numbered according to the decimal system. Equations and displayed expressions are identified by the section number in which they appear followed by a letter. Figures and tables are identified by a section number followed by a roman numeral.

Part 1 of the report is concerned with the application of systems methods to socio-economic processes and, in particular, to a university. It contains a brief non-technical review of the model followed by a full detailed technical description, including the mathematical development.

Part 2 is presented primarily for the reader interested in the use of the model in administration. It includes both general discussion and specific examples of application. The non-technical review in Part 1 (1:2. 1, 1:2. 2, and 1:2. 3) serves as an introduction to the model.

Part 3 is concerned with the computer implementation of the model and therefore is technical in nature.

Documented descriptions of the data processing and simulation programs, including the complete user's guides, are contained in Part 4, Supplements. Also contained in this section are developments having to do with financial aids and faculty records.

All references in the report are included in the numbered bibliography contained as section 5:1 in Part 5 with a project record of materials developed in section 5:2.

Part 6 contains auxiliary reports which were developed during the life of the project. Each document is self-contained and supports the discussions presented in Parts 1, 2, and 3.

Documented listings and sample runs of the operating programs STUVEC, CLASCARD, MSUSIM2, and FACCLS are bound separately and are available upon request from Michigan State University, Division of Engineering Research, at a cost of $25.

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Harold Dahnke - Director of Space Utilization
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Paul Dressel - Director, Office of Institutional Research
John Hoffman - Director, Division of Engineering Research
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Part 1

THE UNIVERSITY AS A SYSTEM

THE UNIVERSITY AS A SYSTEM

1:1 Systems Analysis and Socio-Economic Systems

Traditionally, systems engineers have been concerned with developing the theory, methodology and techniques essential to quantitative analysis, design, and control of workable physical systems. Outstanding accomplishments have been possible because man has learned how to model mathematically the various phenomena involved and how to apply these models in the design and analysis of the system with which he is concerned. In recent times he has furthered his analytical capabilities enormously by the invention and development of high speed computers which aid in processing and analyzing complicated and extensive mathematical models.

The design and development of such complicated systems as our communication systems, power systems and certain aspects of our transportation systems are possible only because these systems can be resolved into a collection of interacting components. Modern system theory is concerned specifically with a discipline for quantitatively analyzing such systems of interconnected components. A great deal of progress has been made, particularly in the last couple of decades, in the development and application of this theory to the design of physical systems. At the same time, it is becoming increasingly more evident to many scientists that our society can also be viewed as a collection of interacting parts, components or sectors, and that we might therefore expect ultimately to model at least limited aspects of them mathematically.

Thus, quantitative system theory has emerged in the past several years as a powerful general discipline applicable to any phenomenon which can be represented symbolically in terms of discrete components and their interconnections. No matter how complex the events studied or how poor our understanding of them, constructing an explicit model of what we think may be happening increases significantly our ability to test various propositions about the considered behavior. The logical form of the model makes it possible to test for internal consistency and unforeseen consequences, for sensitivity to specified changes, and for conformity to various criteria of what we might want the system to accomplish.

Quantitative methods for the analysis of any process, including the socio-economic processes under consideration here, are based on mathematical models, i.e., sets of equations which show the interdependence of the sets of complementary variables that characterize the process or processes under consideration. If the equations are all algebraic in form (linear or nonlinear), the model is characterized as a static model in contrast to a dynamic model which contains at least one differential (difference) equation of any order. If all differential (difference) equations in the model are presented in first-order form, the model is referred to as a state-space model. Dynamic models of this latter form are the most tractable mathematically and computationally. For this reason, they have evolved as the basis for analysis, simulation, control, and optimization concepts and procedures in modern system theory. The extensive literature on simulation, control, and optimization developed by mathematicians and engineers in electronics and aerospace research applies directly to socio-economic systems when they are modeled in this form.

A state-space model describes the behavioral characteristics of a system as a set of relationships among time-functions representing its inputs, outputs and internal state. For discrete time points, the equations have the general form

$$\begin{aligned} \underline{\psi}(t+1) &= F[\overset{\text{system states}}{\underline{\psi}(t)}, \overset{\text{parameters}}{\underline{\alpha}(t)}, \overset{\text{exogenous variables}}{\underline{\beta}(t)}, \overset{\text{control inputs}}{\underline{\gamma}(t)}] \\ \underset{\text{response variables}}{\underline{\theta}(t)} &= G[\underline{\psi}(t), \underline{\alpha}(t), \underline{\beta}(t), \underline{\gamma}(t)] \end{aligned} \tag{1.1a}$$

where $\underline{\psi}(t)$, $\underline{\alpha}(t)$, $\underline{\beta}(t)$, $\underline{\gamma}(t)$ and $\underline{\theta}(t)$ are finite vectors;

$\underline{\psi}(t)$ and $\underline{\psi}(t+1)$ are said to represent the internal state of the system at times t and (t + 1), respectively, and

$\underline{\theta}(t)$ represents the output or response of the system to its state, parameters, and inputs.

If a model of this form is to be derived for a socio-economic system, the total system must be viewed as a collection of interacting subsystems or components no more or less real than the system of interconnected springs and levers in a machine. A model of any such system is developed systematically from the structural features of the system, presented in terms of mathematical models of the components themselves, and a mathematical model of their interconnection pattern. The fundamental axiom of system theory is that the mathematical models of the components identified in the structure are independent of how the components are interconnected. This implies that the various components can be conceptually removed from the system and studied in isolation and that their corresponding models serve as "building blocks" sufficiently simple to be modeled. It is precisely this feature that makes system theory a universal tool of science.

The solution over time of the state model, for any admissible set of time variations in parameters, exogenous variables, or control inputs, establishes the time variation in the system states and responses.

When complete or exact solutions cannot be found because of the large size of the system, intractable mathematical representations, system phenomena that are not well understood, etc., computer simulation techniques may be helpful in arriving at approximate solutions or in assisting the user in experimenting with selected changes in parameters, exogenous variables and control inputs.

The system control problem, in its most general context, is: for some well-defined goal, determined, within the set of all admissible parameters and control inputs, the time sequence of parameters and/or controls required to achieve this goal in an optimum manner. If the controls required are given as an explicit function of the state of the system, they are referred to as a control strategy or policy.

The model and the nature of the control problems encountered in socio-economic systems are identical in form to the control problems encountered in the electronics and aerospace industries. The theory of control has developed rapidly in recent years, especially since the development of the electronic computer, and control systems (implemented by computers) are now widely used to regulate many industrial and technological processes. Thus a broad variety of system control policies and techniques have been developed and are available for application to socio-economic systems.

However, the choice of a control policy for a socio-economic system is particularly challenging. The problem of determination of the goals to be achieved must take into account both the social demands of the population and the economic and cultural needs of the local, national, or world community. In addition, policy-makers must have a clear idea of how the system has been and is operating. Once the goals have been defined, it is necessary to determine how the system inputs and parameters must be modified to achieve these goals. Among all the controllable inputs of the model, those which will induce the desired changes must be identified.

The control problem is further complicated by the large number of exogenous factors affecting the state of a socio-economic system, many of them unmeasurable, and indeed, often unperceived. This implies that the parameters in the model will continually change in an unpredictable manner. The only way to cope with this change is to periodically update the parameters from data on past performance. The control of the system, in this sense, must be adaptive; i.e., control policies are continuously updated to be consistent with the prevailing parameters in the model.

For this type of control of large-scale socio-economic systems, the use of a high-speed computer is clearly essential. In addition to digesting vast quantities of data in a short time, the use of a computer permits simulation of planned changes under newly-observed conditions. Examination of the response under computer simulation may help to avoid decisions that will affect the system in a way that is economically, socially, or politically undesirable.

In recent years, it has become increasingly apparent that our large universities are in need of more economical and more efficient means of management, long-range planning and budgeting. At the same time, notions of "management" have encountered considerable resistance because of the fear of loss of academic freedom and the end of independent planning by the various disciplines. Implicit in this resistance is the notion that independence can be preserved only if the operation of the university can remain too complex and obscure for centralized control. But the time has now been reached when sheer inefficiency of operation and spiraling costs pose a greater threat to academic freedom than does the relinquishing of some control over the material aspects of higher education.

Systems methods are particularly appropriate to this problem. In the following pages, the university is examined as a socio-economic system, to show how modern systems theory can be applied to problems of resource allocation, within the tradition of academic freedom.

1:2 A System Model of the University

1:2.1 A Description of the Model

In order to achieve a state model of the form described in 1:1, the total university system is viewed as a collection of interacting sectors, or components, each of which is related to a specific aspect of operation or function of the university. At the first level of analysis equations are developed for each sector to describe the relationship among the services produced (or functions performed) and the resources required. The sector descriptions are relatively simple in form and may be studied independently. The total model is formed by describing, at a second level of analysis, the constraints or restrictions which the different sectors impose on one another.

The model itself, then, consists of sets of equations which describe the relationship of resources to production, and, based on these, the associated unit costs of production. It is therefore a mathematical description of the way the university utilizes its resources in production. The resources of the university are described, broadly, as personnel, space, and equipment. The products are identified as developed manpower, research, and public or technical services. No attempt is made to define the academic goals of higher education, nor to establish operational measures of "quality". The objective rather is to provide a definitive description of the mechanism by which the resources are, or might be, transformed into the resulting products so that the subjective aspects of the educational process can be more accurately judged. In this respect optimal allocation policies and definitive decision-making procedures that take into consideration quality and academic goals are outside the scope of the model. The model must be regarded only as an aid to the decision maker in making such judgments.

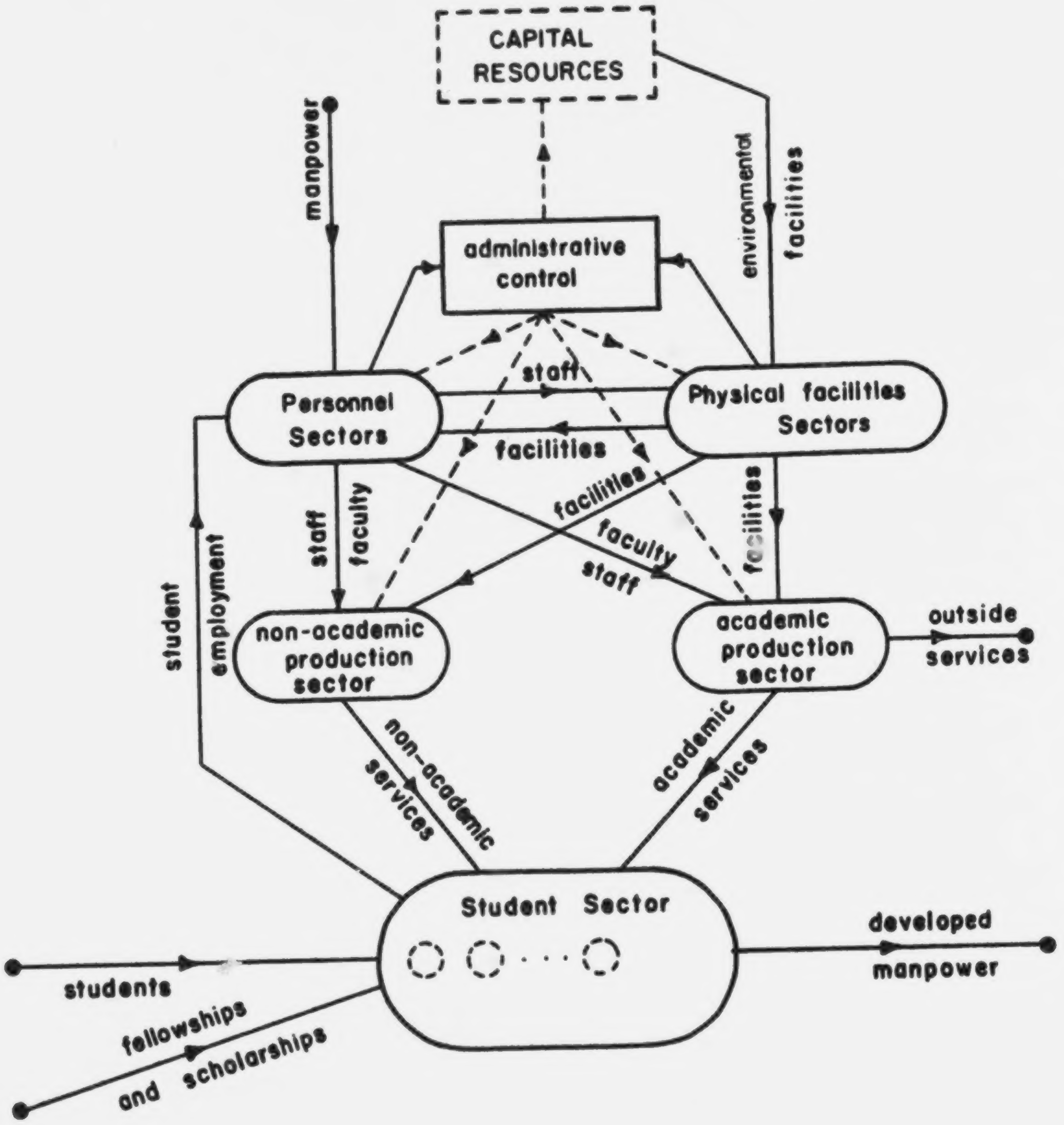
The schematic diagram in Fig. 1:2.1-I identifies the major sectors or components of university activity established by the model and the variables used to determine the behavioral characteristics of each sector. These sectors, it should be noted, are functional and do not represent the administrative divisions of the university.

The model identifies a student sector, or internal demand component, production sectors related to academic and non-academic services, and resource sectors for personnel and physical facilities. In addition, an "administrative control" sector has been indicated as a source of policy decisions.

The equations of each sector contain parameters or coefficients which are related either to human behavioral characteristics or to the operating policies used, or proposed for use, in the allocation of resources.

The following paragraphs provide a brief description of the sector models, including the information contained in and produced by the mathematical descriptions.

The internal state, or condition, of the university at any particular time is described in terms of the distribution of students among the various areas of education and levels of study and the respective average accumulated costs per student of education to that point in time. The equations of the student sector describe the dependence of the enrollment distribution on the previous year's distribution, its


CAPITAL RESOURCES
manpower
environmental facilities
administrative control
staff
Personnel Sectors
Physical facilities Sectors
facilities
facilities
faculty
staff
staff
faculty
facilities
student employment
non-academic production sector
academic production sector
outside services
non-academic services
academic services
Student Sector
students
fellowships and scholarships
developed manpower

—— vector flows of people and services with associated imputed values per unit

---- administrative policy controls

● interfaces with remaining socio-economic process (terminals)

◌ population groups and their imputed values (internal states)

Figure 1:2. 1-I Basic Structure of a Typical Institution of Education as a Socio-Economic Process

dependence on the enrollment choices of new students, and its dependence on available graduate assistantships, fellowships, scholarships, and other financial aids. The form of the equations also allows the inclusion of other factors which influence student enrollment, if they can be identified and described quantitatively.

The model of the student sector also describes the number and educational status of the students who leave the university--their fields of study, matriculation levels and the average "cost," or investment, per student accumulated to the time of departure. Finally, the model of the student sector determines from the enrollment distribution the number of student credits and hours of research-teaching that must be produced to satisfy the demands of the student body.

The parameters (coefficients in the equations) of the student sector depend on the behavioral patterns of the students in shifting from one category to another, in selecting courses, and in response to financial aid.

The student sector model generates a particular pattern of demand for course credits and research-teaching associated with dissertation research. These may be referred to as academic services. Other academic services such as sponsored research, continuing education, or special programs, are similarly demanded by the community outside the university.

The equations of a sector of the model called Academic production describe the relationship between the quantities of academic services produced and the quantities of faculty effort, graduate assistant effort, and environmental facilities such as classrooms, laboratories, and technological equipment, required to produce these academic services. The description of this sector includes the cost of services produced, based on the costs of resources required. These costs determine the cost of education, referred to in the student sector, as well as the cost of sponsored research and other services.

The parameters (coefficients in the equations) of the Academic production sector represent the policies followed by the administration in allocating resources to meet the academic demands. They include, in particular, such ratios as full-time-equivalent faculty per student credit, by rank and field and level.

Services such as housing, registration, counseling, or medical service must also be produced to satisfy student demands. The equations of the sector known as Non-Academic production again indicate the quantities of effort and facilities required to meet these demands, as well as the imputed unit cost of production.

The resources required by the Academic and Non-Academic Production sectors--various types of personnel effort and various types of space or environmental facilities--are in turn produced by the resource sectors of university operation referred to in the model as Personnel and Physical Facilities. To produce faculty teaching effort, for example, the university must utilize not only the "labor" of the academic employees themselves, but also the labor of secretaries and other supporting staff, and the office space and other facilities required to maintain the academic staff on the campus. Equations of the Personnel sector indicate the quantity of each of these resources used to produce a given number of units of effort, of all types, required by the Production sectors.

Information giving the costs of resources required by the production sectors is also included. These costs are based on total requirements. This means, for example, that the cost of a unit of faculty service is computed on the basis of average faculty salary, average cost of office space and equipment, cost of a percentage of supporting secretarial effort, and other secondary costs related to academic personnel. Similarly, the average cost of a classroom unit includes maintenance and operation. To the extent that capital investment costs can be allocated on the basis of use of facilities, they can also be included in the cost of production.

The structure of the system model allows an independent model of capital resource development to be incorporated into the structure of the constraints or allocation patterns can be determined.

Units of effort and facilities are also required by the sector identified as Administrative Control. However, the administrative policy decisions produced as "output" by this sector are not described in quantitative units. Rather, the policy decisions produced by the Administrative Control sector are viewed as allocating the resources. This is achieved in the model by altering the input-output relationship of each sector, i. e. , by setting policy as to how the resource production is allocated to meet the requirements. A decision to change policies of resource allocation becomes, in the model, a change in the production equations themselves.

When the independent descriptions of the sectors are combined, constraints are imposed on the values that the related variables may assume. The credit hours produced by Academic Production are those demanded by the Student sector. The building space used in connection with Physical Facilities is equal to that needed to produce the classroom, laboratory, office, and other space demanded. The use of personnel is similarly constrained. Such a model differs from traditional economic models in that all resources are considered as scarce when compared to demands, and demands are regarded as obligations which must be met. The "inputs" of personnel and physical facilities are considered to be totally utilized in each time period and are therefore regarded as the resources required to meet production, under existing operating policies.

The most interesting and technically difficult constraints in a system are those involving variables which represent both a demand on the system and which are also used as a resource to meet other demands. In the system description such variables appear as feedback loops,---an increase in the variable as a resource feeds an additional demand back into the system. These constraints play an important part in the stability and control of the system.

One such constraint in the system description concerns the composition of the student body. The number of graduate assistants employed by the university is related to the undergraduate student enrollment distribution, through the demand for undergraduate course credits. On the other hand, the enrollment distribution, at least in the graduate levels, depends in part on the availability of graduate assistantships. Therefore, the equations of the model describe a circular relationship, or loop, associated with the employment of graduate assistants. Questions concerning allocation of resources and costs to various student programs can only be answered by descriptions which account for this circular relationship.

The model can be updated periodically in two ways to respond to changes in the institution. First of all, since the total system model is composed of models of separate sectors of activity, the theoretical model itself can be modified by addition, aggregation, or redefinition of its sectors and variables, within the overall mathematical model. Secondly, and more important, the numbers in the equations may be re-evaluated periodically from current data or according to changes in operating policies imposed by the administration.

A detailed description of the model appears in 1:3 and 1:4.

1:2.2 The Control Problem

Formal application of control theory to management and planning for a university is particularly challenging.

When particularized to the model of higher education, optimal control theory addreses itself to such questions as: (1) given the input control vectors, determine within a given set of admissible policy parameters the set or sets of production policies (allocations on limited input resources) that result in minimum cost of education, or (2) given a particular set of production policies, determine within an admissible set the time sequence of inputs and controls that will produce a given change in the output at minimum total cost over a period of T years. Note that within the context of either question one has the freedom to limit the parameters and controls to given values, as dictated by the judgment on the quality of the resulting product and the magnitude of the allowable or available control variables.

The system model is used as the "logic" of computer programs which operate in such a way that the consequences of alternate policies in the allocation of resources and the implementation of designated controls can be evaluated. The model has provisions for including descriptive equations for control factors, and the nature of some of them are identified explicitly. It is certainly well-recognized, for example, that the availability of scholarships, fellowships, and assistantships influences the composition of the student body. These financial aids, therefore, constitute a control factor in the formal sense and are included in the mathematical description. A detailed study of the specific nature of the influence of financial aids is being pursued (see 2:4). In addition, a variety of other factors affect the system. As these other factors are identified and quantified, their influence can readily be incorporated in the mathematical description.

Note the significance of the fact that the policy parameters and controls are known as an explicit function of the state of the system. This implies that the optimal set of production policies and controls can be re-evaluated periodically by simply observing the current state of the system, i. e., the optimal control policy depends upon the present state of the system. It is fixed only when the system is not changing.

It seems unlikely that a rigidly formulated policy of control could, or should, be applied to a social system as complex as a modern university. However, a clear understanding of control theory can lead to the optimal use of techniques developed in mathematics, engineering, and probability, and can help reveal the full advantage of the systems approach to social and economic problems.

1:2.3 The Data Base

In the allocation of resources, administrators may be reacting to any number of variables, such as the number of students, the quality of their preparation, prestige factors, quality of faculty, job opportunities for graduates, and social or scientific urgencies. Whatever the situation may be, one is ultimately forced, in a modeling effort, to use only those variables which are measurable--variables such as hours of lecture and research, student population levels, square feet of building space, faculty man hours and unit costs of resources. Hopefully, some of the less tangible aspects of the system considered in the allocation process can eventually be expressed in terms of data related to these or other measurable variables. But it is difficult to conceive that all aspects of an educational system can be quantified and included in a mathematical model. Consequently, it must be recognized at the outset that any model has limitations as a decision tool and that the results of any experiment with the model must be weighed or tempered by less tangible considerations.

The model presented in this report considers only those features of the educational process that can be characterized in terms of flow rates of numbers of people, goods, and services and their associated unit values as measured in dollars. The problem of quantifying the "quality" and "effectiveness" of the educational program as they relate to administrative and academic policy has received preliminary study, but these variables have not been incorporated into the model. Neither have any behavioral studies been made with respect to student demands.

Even within the framework of quantifiable variables, the model must be regarded as stochastic rather than deterministic, i. e. , the parameters and variables are described in terms of average or expected values. Allocations are based on probable needs and are invariably quantitized with temporary shortages or over-supplies of classroom space, teachers, etc.

The accuracy of any model, of course, rests critically on an accurate and adequate data base from which the parameters in the model can be evaluated. While the mathematical model defines and delineates the data base needed to describe the system parameters and allocation policies, these data are seldom available even for relatively unsophisticated models. Thus, a serious modeling effort also implies a parallel development of data acquisition and processing systems. Further, the extent of the required data base is such that the modeling effort is usually practical only if the data base is available in a form that is addressable by a computer. If the model is to serve as an effective decision tool, the data acquisition system must also include provision for periodic updating.

The parameters of the student sector depend on the behavioral patterns of students in shifting from one class level or area of study to another and in selection of course credits. Machine-addressable student records must include sufficient information to identify the parameters. The parameters of the production sectors are within the control of the administration and consequently, it is not necessary to determine them from past records, except as required to establish the validity of the structural form of the model and to monitor the system to determine what the current operating policies actually are--in contrast to what they were intended to be. As a practical expedient, almost any administrator would want to take prevailing allocation policies as a starting point in any decision making study.

Again, machine addressable files from which prevailing policy parameters can be evaluated are very desirable if not necessary.

The prevailing policy parameters in the Personnel and Physical Facilities sectors are implicit in the accounting records of the university, but to determine them explicitly from manually addressed files is not really practical except for highly aggregated studies. Therefore, extensive use of this sector model in analysis and resource allocation must await further developments in computer based accounting systems.

In section 2:1.2 of the report the development of an integrated data-base is discussed in detail. The development of data files is described in 3:1.

1:2.4 Comparison with Other Efforts in University Modeling

Considerable effort has been devoted to mathematical modeling of various phases of the operation of educational institutions. No attempt is made here to review all such efforts. In many universities, phases of operation such as student scheduling or classroom assignments are now implemented through computer programs which are, of course, based on mathematical models. At the other end of the modeling spectrum are purely theoretical studies designed to promote understanding of the educational process.

The project described in this report may be separated into two distinct phases of mathematical modeling. First, the theoretical development of the state-space model for resource allocation involves the modeling of the behavior of the entire university system, with all its varied activities and functions, and with the interrelationships and constraints they impose on one another. Secondly, based on the theoretical model, computer programs have been developed to illustrate the use of the model in university operation. This second phase of the project is discussed in parts (2) and (3) of the report. Because of its broad scope, the Systems Model for Higher Education differs from or goes beyond previous studies in several respects.

Use of a Markov matrix to describe changes in population distribution has been considered by other investigators [14, 16, 48, 81]. Brown and Savage [16] develop a matrix describing transitions of students in the University of Minnesota from 1958-1959, as part of a study on enrollment prediction. In Merck [81], a Markovian model is used to describe movements of Air Force personnel through categories defined by career field and enlistment terms. Gani [48] presents a theoretical discussion of the use of transition matrices to project enrollments and degrees. The problems of resource allocation and student transitions have been studied through the use of economic input-output models by Stone [112].

The model presented here extends beyond these reported works in several respects: (1) the academic demands placed on the production facilities of the university are given as explicit functions of the population dynamics, by field and level of study; (2) it delineates, in the form of numerical parameters, the allocation policies that are used by the administration to meet these demands and gives administrators the capability to experiment with alternate allocation policies; (3) it is based on real flows and unit costs, rather than on dollar flows, thereby providing the mechanism for investigating the effects of inflationary trends; (4) it identifies a computer-oriented data acquisition and processing system necessary to periodically update the model, evaluate it and make it a realistic tool in decision making; (5) it allows explicit identification of control variables; (6) it is sufficiently general in form to be associated with any university or with a set of institutions operating in parallel. By generalizing even further, the same type of mathematical formulation may be associated with the entire educational system of a nation (see 1:5).

1:3 The Components of the Model

The following sections describe in detail the mathematical development of the component models. In all cases, linear relations among variables have been assumed as a first approximation. Since the system structure has not been completely identified, it is logical to take advantage of the computational simplicity inherent in linear forms. The models can be regarded as reasonably accurate for the small time spans being considered. It is probable that an analysis of appropriate data, collected over a long enough time span, would reveal many non-linear relationships among the variables of the model.

1:3.1 The Student Sector

The internal state of the university system is described in terms of the distribution of students among various levels and fields of education and associated unit costs or imputed values of education received. The state vector is thus a composite of a vector $\underline{s}(t)$ whose coordinates describe student distribution among the various areas of study at various levels during the t^{th} time interval, and a vector $\hat{\underline{s}}(t)$ whose coordinates represent the corresponding imputed value of each student. In view of the many different purposes of the mathematical model, flexibility is maintained in the degree of refinement with which its state is described. "Areas of study," for example, might be individual departments for the purpose of analyzing term-by-term classroom allotment, but the departments might be aggregated into broader classifications for analysis of long-range trends. It may also be desirable to examine the relation of one unit, such as a particular department or college, to other broadly defined areas of study.

The state vector is therefore referred to simply as identifying N categories of student distribution, and imputed values, with the understanding that a category has bivariate classification --- area of study, and level.

Similarly, the "t^{th} time interval" may refer to a term, semester, school year, etc.

The component of the model designated as the Student sector describes the changes in the state of the system from one time period to the next as a function of the state itself, inputs of new students and of services utilized by students in pursuing their academic programs.

1:3.1.1 The Transition Equation

Let

$$\underline{s}(t) = [s_1(t), s_2(t), \ldots, s_N(t)]^T$$

be a subvector of the state vector, where $s_i(t)$ represents the number of students in category i during the t^{th} time interval, and superscript T indicates transpose.

If $p_{ij}(t)$ represents the proportion of those students in the j^{th} category during time (t - 1) who are in category i during the time t, the NxN matrix

$$P(t) = [p_{ij}(t)], \qquad i = 1, \ldots, N; j = 1, \ldots, N$$

describes the transitions between categories for those students who are in the university during time periods (t - 1) and t.

Let n(t) represent the number of new students arriving at the university at time t and let

$$\underline{a}(t) = [a_1(t), \ldots, a_N(t)]^T$$

be the distribution vector for the arrivers, where $a_i(t)$ represents the proportion of the new students who enter category i.

The product

$$\underline{a}(t)\, n(t)$$

is an N-vector whose components represent the number of new arrivals entering the respective categories.

A difference equation representing the transition in student population distribution from time period (t - 1) to time period t may then be wrriten

1:3. 1. 1a $$\underline{s}(t) = P(t)\, \underline{s}(t-1) + \underline{a}(t)\, n(t)$$

where the N-vector $\underline{s}(t)$ gives the student distribution in the N categories during period t.

The basic equation is easily extended to higher order to allow for predictions of student distribution in future time periods. The extended equation accounts for transitions of students in the university at the initial time period and those who enter during subsequent time periods:

1:3. 1. 1b $$\underline{s}(t+m) = \prod_{k=0}^{m} P(t+k)\, \underline{s}(t-1) + \prod_{k=1}^{m} P(t+k)\, \underline{a}(t)\, n(t) + \prod_{k=2}^{m} P(t+k)\, \underline{a}(t+1)\, n(t+1) + \cdots + \underline{a}(t+m)\, n(t+m).$$

The matrix product $\prod_{k=i}^{m} P(t+k)$ is a student transition matrix for a time span of m-i+1 time units. If the pattern of student transitions does not vary with time, so that $P(t) \equiv P$ for all t, the matrix product becomes simply P^{m-i+1}.

1:3.1.2 Control Variables

Equation 1:3.1.1a, the "raw" student transition equation, describes the change in state as a natural progression from one time period to the next. In this case, the matrix P(t) and the vector $\underline{a}(t)$ represent the aggregate decisions or behavior of all students, without regard to cause. So far, no provision has been made for isolating those factors which affect the proportion of students moving from one category to another and those variables which might be considered controls. However, it should be possible to isolate certain factors which influence student decisions, in particular, the decision to choose a certain field of study and the decision to continue with graduate study. If factors are isolated which are subject to control, they may then be regarded as control variables of the system.

As an example of a first step towards identifying controls, it will be assumed that the number of fellowships and graduate assistantships available in any area of study will affect the number of students continuing with or beginning graduate work. The availability of scholarships or tuition discounts in particular areas may affect the decisions of undergraduates as well.

Two vectors of "financial aids" are therefore introduced into the model which will be called control variables:

$$\underline{g}(t) = [\, g_1(t), \; \ldots, \; g_G(t)]^T$$

$$\underline{h}(t) = [\, h_1(t), \; \ldots, \; h_H(t)]^T \; .$$

The entry $g_i(t)$ represents the number of assistantships utilized in classification i during time period t, while $h_j(t)$ represents the number of scholarships or fellowships in classification j. Both variables must be measured in some units proportional to full-time-equivalent units.

The field-level classifications with which financial aids are associated is, in general, an aggregate of the categories used to describe student distribution, depending on the way these aids are awarded. Fellowships and scholarships are typically awarded to an individual, by the university or an outside agency, either with no restrictions as to field of study, or general restrictions such as "science" or "education". Therefore, as a control vector, $\underline{h}(t)$ might contain as few as two components, representing undergraduate and graduate awards. However, graduate assistantships are usually awarded at the discretion of individual departments so that it is useful to identify as many "fields" for assistantships as there are for students. Assuming that no assistantships are offered to undergraduates, there will be only graduate levels represented.

It is possible, with the mathematical framework of the financial aid vectors, to characterize the classification of aids according to other factors than academic field and level. It is entirely possible to designate aid according to source, such as "state", "national", "industrial", etc. The resulting mathematical formulation will be the same, within the student sector of the model. However, difficulties may arise in identifying these variables with variables in other sectors of the model (see 1:3.4.1).

The state equation (1:3.1.1a) may now be modified by writing

1:3.1.2a $$\underline{s}(t) = P(t)\underline{s}(t-1) + \underline{a}(t)\, n(t) + K_1\underline{g}(t) + K_2\underline{h}(t).$$

In this equation the matrices K_1 and K_2 attribute part of the enrollment in each student category to the amount of financial aid available.

The N x G matrix K_1 describes the influence of graduate assistantships on student transitions and on new enrollments and may be written as the sum of two matrices, K_{11} and K_{12}. An entry $k_{ij}^{(11)}$ of K_{11} denotes the number, per single assistantship, of previously enrolled students whose re-enrollment in category i during period t may be attributed to the influence of a single assistantship in category j. The sum

$$k_{1j}^{(11)} g_j(t) + k_{2j}^{(11)} g_j(t) + \dots + k_{Nj}^{(11)} g_j(t) = \sum_{i=1}^{N} k_{ij}\; g_j(t)$$

is the total transition in all categories attributed to assistantships in classification j, whereas

$$k_{i1}^{(11)} g_1(t) + k_{i2}^{(11)} g_2(t) + \dots + k_{iG}^{(11)} g_G(t) = \sum_{j=1}^{G} k_{ij}\; g_j(t)$$

is the total transition into category i attributed to graduate assistantships.

An entry $k_{ij}^{(12)}$ of K_{12} is the number, per assistantship, of new entrants into category i which may be attributed to a single assistantship in classification j.

The N x H matrix $K_2 = K_{21} + K_{22}$ describes the influence of fellowships and scholarships on student enrollments in similar fashion.

The assumption is made that if enrollment in a particular category is attributed to financial inducement, the student would have left or would not have entered the university in the absence of financial aid. The model does not depict alternative choices within the system related to financial aid. It is possible that some students, whose choice of field of study depends on financial inducement, would have remained in the university in a different subject area without the financial aid. If this pattern of behavior is found to be significant, the state equation must be altered.

If it is correct to assume that $\underline{g}(t)$ and $\underline{h}(t)$ are control variables, then, as equation 1:3. 1. 2a indicates, university administrators can influence the state of student distribution by increasing or decreasing the number of graduate assistantships or other forms of financial aid.

Computation of the entries in K_1 and K_2 matrices is discussed in 1. 4. 6.

No attempt has been made at the present time to identify and isolate other variables which influence or control student enrollments. Factors such as economic trends, labor demands, or selective service policies might be considered. If they can be represented by quantitative vectors, and if their influence can be measured in some way, they can be included linearly by adding terms to equation 1:3. 1. 2a.

In the model developed here, admission of new students is regarded as uncontrolled, except perhaps for the total number of students admitted, $n(t)$. However, if it is possible for the administration to control the distribution of new students, by admitting them in predetermined numbers to various fields and levels, the vector $\underline{a}(t)\ n(t)$ becomes a control variable.

1:3.1.3 Output of Educated Manpower

We turn now to the determination of the number of students of each category departing from the institution during or at the end of the t^{th} time period. In the "raw" student transition equation, (1:3.1.1a), the entries in the matrix P(t) represent the total student transitions, with

$$\sum_{i=1}^{N} p_{ij}(t)$$

being the total proportion of students in category j during time (t-1) who transfer to other categories within the university. The difference

$$\delta_j(t) = 1 - \sum_{i=1}^{N} p_{ij}(t)$$

represents the proportion of students of category j who have departed from the university by period t. Letting D(t) be the NxN diagonal matrix whose j^{th} diagonal element is $\delta_j(t)$, the vector $\underline{d}(t)$ of manpower departing from the institution, by field and level, is represented as a linear function of the student vector,

1:3.1.3a $$\underline{d}(t) = D(t)\,\underline{s}(t-1)$$

where

$$\underline{d}(t) = [d_1(t), \ldots, d_N(t)]^T.$$

When part of the student transition is attributed to causal factors, as in equation 1:3.1.2a, the student transition matrix P(t) represents only "free" transitions of students from one category to another. The matrix D(t), reflecting the proportion of students in each category who depart from the university, is similarly modified. Since its diagonal elements $\delta_j(t)$ are equal to the difference

$$1 - \sum_{i=1}^{N} p_{ij}(t),$$

the product

$$D(t)\,\underline{s}(t)$$

now represents the number of students in each category who would leave the university in the absence of any financial aid. To correspond with the new state-vector equation, the output-vector equation is now

1:3.1.3b $$\underline{d}(t) = D(t)\,\underline{s}(t) - K_{11}\underline{g}(t) - K_{21}\underline{h}(t).$$

The coefficients in K_{11} and K_{21} reflect the influence of assistantships and other aids awarded to students already within the university system, who would not otherwise continue (see 1:3.1.2).

Thus, administrators can determine the effect of changes in the number of graduate assistantships or fellowships on the manpower output of the university.

1:3.1.4 Credit Demands

Each student imposes upon the university a demand for credits of course work. In addition, if the student's academic program includes research efforts, the faculty will be called upon to provide "research-teaching" to direct these efforts. Let $\underline{c}(t)$ and $\underline{r}(t)$ be vectors representing course and research credits respectively for appropriate fields and levels.

The field-level categories used to describe credits demanded may differ from the student population categories. Course levels, for example, may be designated simply as lower undergraduate, upper undergraduate, and graduate. The field designations of courses may differ from the major field designations of students, depending on the record-keeping practices of the university (see 3:1 on Michigan State University class-card files). If the model is to be used to study allocation of resources, then it is useful to classify courses on the same basis as the "production units," e. g., departments or colleges, which produce the courses to satisfy student demands (see 1:3. 2. 1). The subsequent development assumes that m field-level categories have been established for course credits and research-teaching credits.

If it is assumed that the unconstrained demands imposed on the university are directly proportional to the components of the state vector $\underline{s}(t)$, then the number of credits for each category may be written as a vector

$$\begin{bmatrix} \underline{c}(t) \\ \\ \underline{r}(t) \end{bmatrix} = \begin{bmatrix} C \\ \\ R \end{bmatrix} \underline{s}(t) \tag{1:3. 1. 4a}$$

where C and R are m x N matrices.

Each entry c_{ij} of the matrix C denotes the average number of credits of course type i taken by a student in category j; i = 1, ..., m; j = 1, ..., N. The j^{th} column of C gives the average distribution of course credits in all areas of study demanded by students in category j; the i^{th} row of C gives the average distribution of demand by students in all categories for course credits of type i. The matrix R gives similar data for research-teaching. It is assumed that research-teaching is measured in terms of research credits or similar units. The entries in the vectors $\underline{c}(t)$ and $\underline{r}(t)$ denote total number of student credits demanded (number of credits multiplied by the number of students registered) for each of the m types of course established.

1:3.1.5 Cost of Education

Finally, as part of the demand sector, it is desirable to impute a value, or total accumulated investment, to each student in the institution. These values are expressed in terms of the cost, in dollars, of teaching hours and support facilities, and in terms of the value assigned to a student on entering the institution.

Let the scalar $\hat{n}(t)$ represent the average value of the educational investment in a student who is beginning college. It is assumed that the imputed value of a student entering at an advanced level is the same as a corresponding student developed within the institution. Added to the student's initial value are the values of course and research-teaching credits which contribute to his education. The vectors $\hat{c}(t)$ and $\hat{r}(t)$ denote the unit costs of course credits, $\underline{c}(t)$, and research-teaching credits, $\underline{r}(t)$, for the m categories of the university program. Similarly

$$\underline{\hat{s}}(t) = [\hat{s}_1(t), \ldots, \hat{s}_N(t)]^T$$

is a subvector of the state vector whose coordinates denote the average cost or imputed unit value of education of a student in each of the N categories.

From the standpoint of both system theory and accounting practice, the components of $\underline{\hat{s}}(t)$ are taken as negative numbers, representing unit costs of output of the demand sector, whereas the values of teaching, research, and new students are positive, representing input to the demand sector.

Consider the value imputed to a student in category i during the t^{th} time interval. This value is expressed in terms of a weighted average of the values attributed to students who entered category i from all other categories, using the values imputed during the $(t-1)^{th}$ time interval, and adding the value accumulating during the t^{th} time interval. The coefficients in the weighted average are taken as the proportions of students entering category i from the other categories.

Letting

$$q_{ij}(t) = \frac{p_{ij}(t)\ s_j(t-1)}{s_i(t)}$$

and letting v_i represent the value added during time period t, the unit value for category i is

$$\hat{s}_i(t) = \sum_{j=1}^{N} q_{ij}(t)\ \hat{s}_j(t-1) + \frac{a_i(t)\ n(t)}{s_i(t)}\ \hat{s}_i(t-1) - v_i(t).$$

The average imputed value or cost for all categories may be written in vector form:

1:3. 1. 5a $$\underline{\hat{s}}(t) = Q(t)\ \underline{\hat{s}}(t-1) + \underline{\hat{a}}(t) - C^T\ \underline{\hat{c}}(t) - R^T\ \underline{\hat{r}}(t).$$

Q(t) is a matrix with entries $q_{ij}(t)$, and $\underline{\hat{a}}(t)$ is a vector with components

$$\hat{a}_i(t) = \frac{a_i(t)\ n(t)}{s_i(t)}\ \hat{s}_i(t-1).$$

$\underline{\hat{a}}(t)$ represents the value of education of entering students.

The products $C^T\underline{\hat{c}}(t)$ and $R^T\ \underline{\hat{r}}(t)$ represent the costs of course credits and research teaching credits demanded during time period t. The costs are aggregated for each of the N student categories. The computation of unit cost entries for $\underline{\hat{c}}(t)$ and $\underline{\hat{r}}(t)$ is discussed in 1:3. 2. 1, which considers the aggregation of costs according to the m academic production categories.

1:3.1.6 Parameters of the Student Sector

The matrix P(t) of student transition proportions and the vector $\underline{a}(t)$ of new student distribution may be established from university record files (see 2:1.2, 2:1.3, 3:1). P(t) is considered to contain behavioral parameters reflecting aggregate student behavior and is therefore not subject to administrative control. The vector $\underline{a}(t)$ must also be considered a vector of behavioral parameters, except in those cases where student admissions to particular fields or levels can be controlled. Note that if admissions are controlled, the vector $\underline{a}(t)\,n(t)$, distribution of new students, becomes a control vector of the model.

The matrices K_{11}, K_{12}, K_{21}, and K_{22} which describe the influence of financial aids on enrollment are difficult to determine. The same is true of the measurement of influence of any factors which affect enrollments. The relation of such variables to student distribution may be examined by applying techniques such as regression analysis to existing data. A method is suggested in 1:4 for computing the entries of the matrices associated with financial aid. This method is based on an evaluation of the proportions of students in each enrollment category whose presence in the university may be attributed to financial aids of various kinds. This proportion will differ from the proportion actually receiving financial aid, since some students who receive aid would be present, even without the aid. A detailed review of attempts to establish financial aid parameters is presented in 2:4.

The course credit distribution parameters in the matrix

C are established from university records of course enrollments in any particular time period. These values are partly controllable by administrative decision on degree requirements. However, to the extent that electives are permitted in student programs, the entries in C must be regarded as behavioral parameters. The values in R, determined by enrollment under research or "Special Problems" numbers, may not accurately reflect demands for research-teaching in connection with degree programs. However, this seems the most feasible method of establishing the parameters from university records as they are now kept.

1:3.2 The Production Sectors

1:3.2.1 Academic Production

In concept, the demands of the student population for course credits and research teaching, as described in 1:3.1.4, are met by production units associated with areas of study used in the model. The resources required to meet these output demands are classified into three types: faculty effort, graduate assistant effort, and support facilities (environment). In addition, these academic production units produce a variety of outputs which are not demanded or "consumed" within the university. The production of sponsored research under contract for government or industry is perhaps the major exogenous output. A university may also be called upon to provide extension courses, continuing education programs, international aid, and a variety of other services.

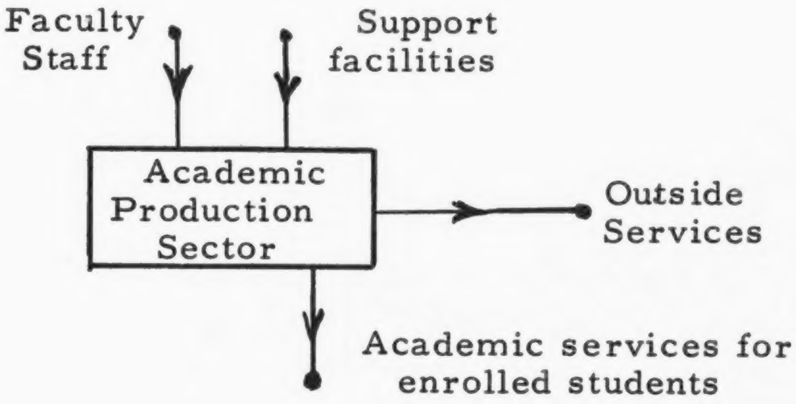
In order to develop a model of academic production, it is necessary to determine a method of measuring resource requirements as a function of production. The model described here measures required faculty and graduate assistant effort in terms of student credits produced. Two alternative methods are presented for measurement of environmental facilities.

In the first method, environmental facilities are assumed to be a function of student credits produced. Using this relationship, a unit cost of student credits can readily be determined, from the unit costs of various types of facilities and the cost of faculty and staff effort. The resulting cost vector $\underline{\hat{c}}(t)$ may then be used in equation 1:3.1.5a to evaluate costs of education.

However, in planning for the facilities required in any time period, it is often more useful to compute required physical facilities, such as classroom stations, on the basis of student hours, i.e., number of students multiplied by the number of hours per week the facility is used, rather than on the basis of student credits.

If most courses meet regularly in classrooms for a number of hours proportional to course credits, there is little difference in the two methods. But it is becoming increasingly common to find courses which combine formal class meetings with independent work, so that a course carrying 4 or 5 credits meets, perhaps, only two hours a week. More important is the fact that demands for auxiliary facilities such as library volumes or language laboratory stations are not directly related to course credits. Therefore, a second method of measuring the use of environmental facilities is based on an estimated "usage" of each type of facility for each area of study identified.

A schematic diagram of the academic production sector as an input-output sector is shown below:


Faculty Staff
Support facilities
Academic Production Sector
Outside Services
Academic services for enrolled students

Because of the use of graduate assistants, the system model will contain a "loop" linking the student sector and production sector, with graduate students acting as both producers and consumers. This is described more fully in 1:3.4.

Assume the M areas of production have been defined by the model. These areas may coincide with colleges, departments, or any useful aggregations. A model of a single production unit will be described first, followed by a description of the total sector model. The vector

$$\underline{f}(t) = [f_1(t), \ldots, f_k(t)]^T$$

represents the number of units of faculty effort, at k faculty ranks. required during the t^{th} time interval. These units are considered to be proportional to the full-time equivalent of faculty used in academic services. The vector

$$\underline{g}'(t) = [g'_1(t), \ldots, g'_\ell(t)]$$

represents units of required graduate assistant effort in ℓ different classifications such as graduate study level, size of stipend, or other factors. In many cases, it will be sufficient to consider only one classification of graduate assistants for each production unit. A vector

$$\underline{e}_1(t) = [e_{11}(t), \ldots, e_{1r}(t)]$$

represents r major components of environmental facilities, such as classroom and laboratory positions, library book use and study space, auditoria, and use of computers and audio visual equipment.

Before a physical resource can be included in the model, a method must be devised for measuring its use. Many universities have established records on the use of classroom and laboratory space, but measurement of the use of such things as programmed-learning computers and closed-circuit TV must also be included if the model is to be useful in planning and innovation. It has been traditional for universities to consider space requirements separately from other facilities. But as universities grow, it becomes increasingly urgent to develop alternatives to formal classroom meetings, taking advantage of new communication media and other technological equipment. The model therefore considers space requirements as only a part of the total environmental resources.

Measurements of use of environmental facilities may be recorded in terms of "usage units" required for each type of facility. Classroom and laboratory stations, and study areas, may be measured in terms of the product of the number of stations and number of hours per week of use. Library use may be measured in book-days. Closed circuit TV may be measured in terms of use of TV-equipped classrooms, or in terms of hours of equipment usage. For each type of facility, a standardized and consistent measurement must be devised.

A vector

$$\underline{o}(t) = [o_1(t), \ldots, o_s(t)]$$

denotes s categories of "outside" services such as research under grants, or seminars for industrial groups, which are "purchased" from the university. Grants and seminars may be measured in terms of equivalent full-time senior faculty effort contracted for under the grant. Course credits and research teaching are again represented by vectors $\underline{c}(t)$ and $\underline{r}(t)$. If the classification of courses and research teaching by field corresponds to the M areas of study identified by production units, the production unit model may include only the appropriate sub-vectors of $\underline{c}(t)$ and $\underline{r}(t)$.

The required personnel efforts and environmental facilities may now be described as a function of services produced:

1:3. 2. 1a
$$\begin{bmatrix} \underline{f}(t) \\ \underline{g}(t) \\ \underline{e}_1(t) \end{bmatrix} = \begin{bmatrix} F_1 & F_2 & F_3 \\ G_1 & G_2 & G_3 \\ E_1 & E_2 & E_3 \end{bmatrix} \begin{bmatrix} \underline{c}(t) \\ \underline{r}(t) \\ \underline{o}(t) \end{bmatrix}$$

The parameter matrices F_j and G_j, $j = 1, 2, 3$, may be established at any time from appropriate university data files, and entries are input-output ratios. Ideally, these files attribute percentages of total effort of faculty and graduate assistants to various functions such as undergraduate teaching, sponsored research, or administration. These percentages could then be aggregated into full-time-equivalent units. However, it is unlikely that such ideal data can be collected in a consistent manner. An attempt at using data obtained by faculty self-evaluation is described in 4:5.3. An alternative scheme is to use an effort-breakdown determined mainly according to source of salary. Thus, for example, a faculty member working under a half-time research contract would be regarded as having half his "effort" available for research and half available for teaching. This breakdown would be meaningful in terms of effort available for assignment to academic duties. The problem still remains of attributing effort to whatever levels of course work are identified.

Environmental facilities may alternatively be measured as a function of student enrollments (rather than student credits) and outside services.

Let EN be an n x N matrix whose n rows correspond to the classification of courses and research teaching established by the vectors $\underline{c}(t)$ and $\underline{r}(t)$. The N columns correspond to the N categories of student enrollment established by the state vector. The ik^{th} entry is the proportion of students in category k who enroll in course-type i. EN is thus an average course-selection parameter matrix, and the product

$$\underline{en}(t) = [EN]\ \underline{s}(t)$$

is a vector giving the total number of students enrolled in each type of course.

Let U be a J x n matrix whose n columns correspond to course classifications. The J rows of U correspond to J types of environmental facilities. The ij^{th} entry of U is the average number of hours (or other units) per week that a student in course classification j requires of facility of type i. Many of these entries may be determined directly from class schedules. U may be regarded as a usage parameter matrix. The product

$$\underline{u}(t) = U\ \underline{en}(t)$$

is a vector whose j^{th} entry is the total number of usage-units per week demanded of facility of type j. The use of environmental resources in academic production is established as

1:3. 2. 1b $$\underline{e}_1(t) = E'\ \underline{u}(t) + E_3\ \underline{o}(t)\ .$$

The entries in E' are ratios of units required to units of facility assigned, and yield parameters on degree of utilization.

In the preceding paragraphs, a model has been developed in relation to a single academic unit. An aggregate model of academic production is identical in form, except that vectors such as $\underline{f}(t)$, $\underline{g}'(t)$, and $\underline{e}_1(t)$ appear as the direct sum of vectors of the individual units.

1:3. 2. 2 Cost of Academic Production

The unit costs of faculty and graduate assistant effort used in academic production are established by the Personnel sector model, and include salary, contingent costs of office space, secretarial support and other resources. These costs are denoted by vectors $\hat{\underline{f}}(t)$ and $\hat{\underline{g}}'(t)$. Average salary scales may also be used as a first estimate to establish unit costs.

The unit costs of environmental facilities are more difficult to determine, and require development of an appropriate accounting system. The model of the Physical Facilities sector suggests a form for determining cost of facilities, $\hat{\underline{e}}_1(t)$.

$$\text{cost of production} \quad \begin{bmatrix} \hat{\underline{c}}(t) \\ \hat{\underline{r}}(t) \\ \hat{\underline{o}}(t) \end{bmatrix} = - \begin{bmatrix} F_1 & F_2 & F_3 \\ G_1 & G_2 & G_3 \\ E_1 & E_2 & E_3 \end{bmatrix}^T \begin{bmatrix} \hat{\underline{f}}(t) \\ \hat{\underline{g}}'(t) \\ \hat{\underline{e}}_1(t) \end{bmatrix} \quad \text{cost of resources}$$

1:3. 2. 2a

This set of equations represents the costs of course credits, research-teaching, and outside services as linear combinations of the unit costs of faculty, graduate assistants, and environmental facilities.

Consistent with the procedures already established, the costs of products of the academic production sector are taken as negative numbers.

1:3. 2. 3 Parameters of the Academic Production Sector

The entries of matrices F_k, G_k, and E_k, $k = 1, 2, 3$, are coefficients of proportionality defined by the context of the units used in measuring the flows of resources and products. These coefficients are of particular importance, since they represent administrative policy parameters used in allocating resources to meet demands.

For purpose of illustration, assume that f_k^{ij} and g_k^{ij} are corresponding entries of F_k and G_k. Ratios of faculty to graduate assistant effort in teaching, research teaching, and outside service programs are, respectively, f_1^{ij}/g_1^{ij}, f_2^{ij}/g_2^{ij}, and f_3^{ij}/g_3^{ij}. Technical innovations in education are reflected in the model by changes in the ratios of faculty effort to support facilities. No one can predict how these ratios will change with time. They are actually "policy coefficients" that can be changed in the model during simulation experiments.

1:3.2.4 Services Sector (non-academic production)

In any university, a variety of activities may be designated as "non-academic production," and the nature of this sector will differ from one institution to the next. A model for non-academic production can best be developed in relation to a specific university and its administrative needs. In fact, the division of administrative responsibility may suggest the development of several sectors, independently modeled, for various areas of activity.

No attempt has been made as yet to model non-academic production in detail. The suggested sector model given below indicates areas of production which are directly related to the number and distribution of students in the university. The demand for these products is then considered to be proportional to the components of the state vector $\underline{s}(t)$. The model is similar in form to 1:3.2.1a for academic production.

The non-academic production areas are denoted by vectors $\underline{p}(t)$, including all processing, registration and evaluation services; $\underline{r}(t)$, which includes all residential and food services; and $\underline{m}(t)$, a vector of units of social and medical services. The number of units of each service required is proportional to the distribution of students:

1:3.2.4a

$$\begin{bmatrix} \underline{p}(t) \\ \underline{r}(t) \\ \underline{m}(t) \end{bmatrix} = \begin{bmatrix} M_1 \\ M_2 \\ M_3 \end{bmatrix} \underline{s}(t)$$

The Non-Academic Production sector utilizes as resources, personnel effort $\underline{k}(t)$ and environmental facilities $\underline{e}_2(t)$:

$$\begin{array}{l} \text{Personnel effort} \\ \text{Environmental facilities} \end{array} \begin{bmatrix} \underline{k}(t) \\ \underline{e}_2(t) \end{bmatrix} = \begin{bmatrix} \theta_1 & \theta_2 & \theta_3 \\ E_1' & E_2' & E_3' \end{bmatrix} \begin{bmatrix} \underline{p}(t) \\ \underline{r}(t) \\ \underline{m}(t) \end{bmatrix} \begin{array}{l} \text{Processing and Registration} \\ \text{Residential} \\ \text{Social and medical} \end{array}$$

1:3.2.4b

The cost of the services demanded is determined as a function of the resources utilized in production.

$$\text{Cost of services} \begin{bmatrix} \hat{\underline{p}}(t) \\ \hat{\underline{r}}(t) \\ \hat{\underline{m}}(t) \end{bmatrix} = - \begin{bmatrix} \theta_1 & \theta_2 & \theta_3 \\ E_1' & E_2' & E_3' \end{bmatrix}^T \begin{bmatrix} \hat{\underline{k}}(t) \\ \hat{\underline{e}}_2(t) \end{bmatrix} \text{Cost of resources}$$

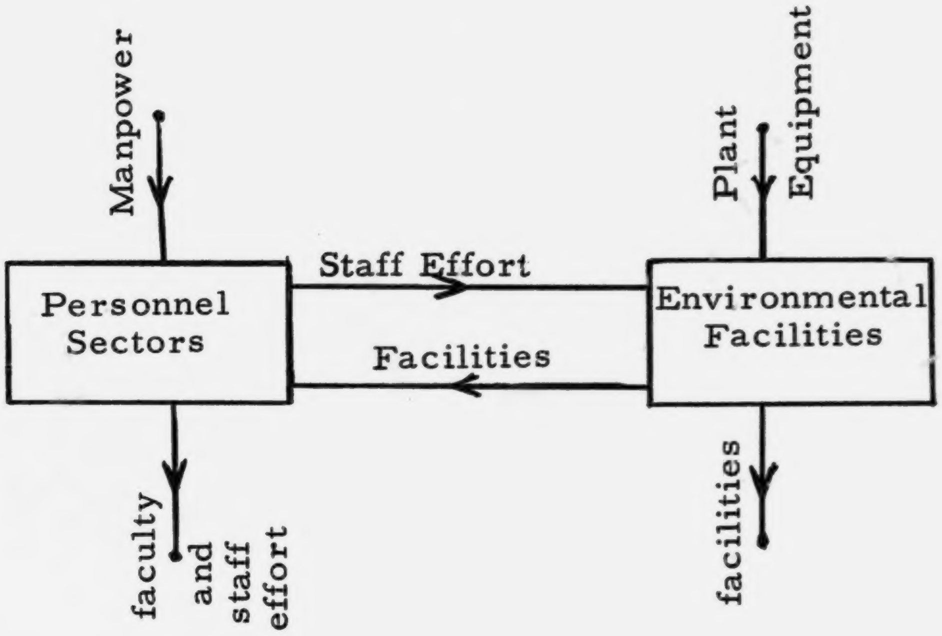
1:3.2.4c

The cost of non-academic services has not been included in equation 1:3.1.5a which establishes a unit cost of education. The vector $\hat{\underline{s}}(t)$ includes only academic costs. However, non-academic costs may be determined from equation 1:3.2.4a:

$$\hat{\underline{s}}'(t) = M_1^T \hat{\underline{p}}(t) + M_2^T \hat{\underline{r}}(t) + M_3^T \hat{\underline{m}}(t).$$

1:3.3 Resource Sectors

The production sectors described in 1:3.2 require inputs referred to as personnel effort and environmental facilities. These production resources are supplied by the conceptual "resource sectors" of university operations. In these sectors, the aggregated labor of many types of personnel and the aggregate of university building space and equipment are allocated as effort units and physical facility units to the various production areas, as shown schematically below:


Manpower
Plant
Equipment
Staff Effort
Personnel Sectors
Environmental Facilities
Facilities
faculty and staff effort
facilities

1:3.3.1 Personnel Sector

Flows into the personnel sector are flows of "labor" and environmental facilities, derived from three different sources. One set of labor flows, measured in full-time-equivalence units, derives from outside of the system in the form of efforts of faculty, office staff, maintenance staff and other employees. A second set of labor flows derives from students being processed in the student sector and takes the form of feedback from graduate assistants and student employees. The third set of flows is from the physical facilities sector. Some of these physical facilities consist of units of space, such as office space, which are used purely in support of personnel and not directly used in academic or non-academic production. In addition, there are flows of equipment (e. g., desks, office machines, automobiles) used in support of personnel, rather than in production.

In the model of the personnel sector, these three sets of flows are identified by three vectors, $\underline{w}$, $\underline{y}$, and $\underline{e}_3$, which may, in turn, be partitioned into sub-vectors denoting appropriate categories of flow. The vector $\underline{w}(t)$ may be partitioned into academic staff classifications, defined by rank and area of specialization, and non-academic classifications such as clerical-technical, administrative-professional, and laborers. The categories of personnel chosen must be related closely to the university's budgeting classifications, if the model is to be used in budgeting.

Also, flows of equipment into the personnel sector must be carefully defined to include only equipment needed for personnel, and not equipment used by personnel in production or maintenance.

The set of flows may be designated as follows:

$$\begin{bmatrix} \underline{w} \\ \\ \underline{y} \\ \\ \underline{e}_3(t) \end{bmatrix} = \left[\begin{array}{l} \underline{w}_1(t) \\ \underline{w}_2(t) \\ \underline{w}_3(t) \\ \hdashline \underline{y}_1(t) \\ \underline{y}_2(t) \\ \hdashline \underline{z}_1(t) \\ \underline{z}_2(t) \end{array}\right] \begin{array}{l} \left.\begin{array}{l} \text{Academic staff} \\ \text{Non-academic (office) staff} \\ \text{Maintenance staff} \end{array}\right\} \text{From outside system} \\ \left.\begin{array}{l} \text{Graduate assistants} \\ \text{Student employees} \end{array}\right\} \text{From Student Sector} \\ \left.\begin{array}{l} \text{Office space} \\ \text{Equipment} \end{array}\right\} \text{From Physical Facilities Sector} \end{array}$$

As in other sectors of the model, the categories may be aggregated arbitrarily, with the constraint that the categories of personnel should be no finer than the production areas of the academic production sector.

Academic staff is here meant to include all those with faculty status, according to university regulations, and may include personnel involved in functions such as counselling, library operation, health services, and athletics, as well as teaching faculty. The distinction between non-academic office staff, and maintenance and operation staff, must be carefully defined, since in some cases the distinction will not be clear. Again, the traditional budgeting practices can be a useful guide.

Flows out of the personnel sector are units of "effort", considered here as percentages of full-time units of labor. These effort flows are described in terms of functions of personnel:

$$\left[\begin{array}{c}\underline{f}(t)\\ \underline{g}'(t)\\ \underline{a}(t)\\ \underline{\ell}(t)\\ \underline{k}(t)\end{array}\right]\quad\begin{array}{lll}\left.\begin{array}{l}\text{Faculty academic effort}\\ \text{Graduate assistant academic effort}\end{array}\right\} & & \text{to Academic Production}\\ \text{Administrative effort} & - & \text{to Administrative Control}\\ \text{Maintenance and operation} & - & \text{to Physical Facilities}\\ \text{Student non-academic services} & - & \text{to Non-academic Production}\end{array}$$

As a first approximation, a linear model has been developed to describe the input-output relations. In any particular university, the theoretical modeling must be based on a detailed study of types of work pursued by each category of personnel. However, since the utilization of the model is dependent on files of current data, periodically renewed, consideration must be given to the degree of detail in which personnel can be expected to report break-downs of their effort. As explained in 1:2.3, a data-base is required to evaluate the coefficients (parameters) in the model, which is consistent and which can be periodically updated. Therefore, while very detailed studies of personnel effort have useful purposes, a model for resource allocation must describe average division of effort based on aggregated data. It cannot be expected to account for personal discrepancies or individual tastes.

Administrative effort refers specifically to administrative (rather than academic) decision-making, planning, and control. Curriculum planning at the department level, for example, is regarded as academic. Much of the effort of office staff members is expended in support of academic staff activity and therefore $\underline{w}_2$ is partly a function of $\underline{w}_1$. However, the model indicates that office staff also engage in operation of equipment and in student services.

The flows of environmental facilities into the personnel sector are a function of the flows of personnel into the sector and are approximated by the linear functional relations

$$\begin{aligned}
\underline{w}_1(t) &= A_1\underline{f}(t) + A_3\underline{a}(t) + A_5\underline{k}(t)\\
\underline{w}_2(t) &= B_1\underline{w}_1(t) + B_4\underline{\ell}(t) + B_5\underline{k}(t)\\
\underline{w}_3(t) &= U_4\underline{\ell}(t) + U_5\underline{k}(t)\\
\underline{y}_1(t) &= V_2\underline{g}'(t) + V_5\underline{k}(t)\\
\underline{y}_2(t) &= W_4\underline{\ell}(t) + W_5\underline{k}(t)\\
\underline{e}_3(t) &= Y_1\underline{w}_1(t) + Y_2\underline{w}_2(t) + Y_3\underline{y}_1(t)
\end{aligned}$$

These six equations can be recombined to form a model of the Personnel sector

1:3. 3. 1a

$$\text{Personnel}\left\{\begin{bmatrix}\underline{w}(t)\\ \\ \underline{y}(t)\end{bmatrix}\right. = \left[\begin{array}{c}\underline{w}_1(t)\\ \underline{w}_2(t)\\ \underline{w}_3(t)\\ \hdashline \underline{y}_1(t)\\ \underline{y}_2(t)\end{array}\right] = \begin{bmatrix}A_1 & 0 & A_3 & 0 & A_5\\ B_1A_1 & 0 & B_1A_3 & B_4 & B_1A_5+B_5\\ 0 & 0 & 0 & U_4 & U_5\\ 0 & V_2 & 0 & 0 & V_5\\ 0 & 0 & 0 & W_4 & W_5\end{bmatrix}\left.\begin{bmatrix}\underline{f}(t)\\ \underline{g}'(t)\\ \underline{a}(t)\\ \underline{\ell}(t)\\ \underline{k}(t)\end{bmatrix}\right\}\text{Effort}$$

1:3. 3. 1b

$$\begin{array}{l}\text{Environ-}\\ \text{mental}\\ \text{Facilities}\end{array}\quad [\underline{e}_3(t)] = [\,Y_1 \mid Y_2 \mid Y_3\,]\begin{bmatrix}A_1 & 0 & A_3 & 0 & A_5\\ B_1A_1 & 0 & B_1A_3 & B_4 & B_1A_5+B_5\\ 0 & V_2 & 0 & 0 & V_5\end{bmatrix}\begin{bmatrix}\underline{f}(t)\\ \underline{g}'(t)\\ \underline{a}(t)\\ \underline{\ell}(t)\\ \underline{k}(t)\end{bmatrix}$$

In equations 1:3.3.1a and 1:3.3.1b, capital letters indicate matrices of parameters whose coefficients represent such information as proportion of academic staff effort devoted to administration, ratio of academic staff to supporting staff, or space required to support academic staff members in various categories. They are therefore policy parameters, subject to administrative control.

Let the input cost vectors $\underline{\hat{w}}(t)$ and $\underline{\hat{y}}(t)$ denote average salaries as determined from appropriate records and $\underline{e}_3(t)$ the cost of environmental facilities as determined from a model of the physical-facilities resource sector. The unit costs of effort, including both salary or wages and the cost of office space or equipment needed to support the employees' presence at the institution is given by

1:3.3.1c

$$\text{Cost of units of effort}\left\{\begin{bmatrix}\underline{\hat{f}}(t)\\ \underline{\hat{g}}'(t)\\ \underline{\hat{a}}(t)\\ \underline{\hat{\ell}}(t)\\ \underline{\hat{k}}(t)\end{bmatrix}\right. = -[\mathcal{A}^T \vdots\, \mathcal{D}^T \mathcal{B}^T]\begin{bmatrix}\underline{\hat{w}}(t)\\ \underline{\hat{y}}(t)\\ \underline{\hat{e}}_3(t)\end{bmatrix}\begin{matrix}\left.\begin{matrix}\\ \\ \end{matrix}\right\}\text{Cost of personnel}\\ \text{Cost of environmental facilities}\end{matrix}$$

where

$$\mathcal{A}^T = \begin{bmatrix} A_1 & 0 & A_3 & 0 & A_5 \\ B_1A_1 & 0 & B_1A_3 & B_4 & B_1A_5+B_5 \\ 0 & 0 & 0 & U_4 & U_5 \\ 0 & V_2 & 0 & 0 & V_5 \\ 0 & 0 & 0 & W_4 & W_5 \end{bmatrix}^T$$

and

$$\mathcal{A}^T\mathcal{B}^T = \left[\begin{array}{ccc} A_1 & 0 & A_3 \\ B_1A_1 & 0 & B_1A_3 \\ 0 & V_2 & 0 \end{array}\right] \begin{array}{cc} 0 & A_5 \\ B_4 & B_1A_5+B_5 \\ 0 & V_5 \end{array}{}^{T} [Y_1 \quad Y_2 \quad Y_3]^T$$

1:3.3.2 Physical Facilities

The major types of space facilities in the university have been classified and units of measure have been developed, but as already indicated in 1:3.2.1 the classification and unit measures of technological equipment used in education is a problem still to be solved. Consequently, the model of a physical facilities sector as given here is structured only in general form.

Flows into the physical facilities sector are represented by vectors denoting appropriate categories of space and equipment and of personnel effort devoted to maintenance and operation. Flows out of the sector indicate space and equipment utilized in academic and non-academic production, administrative control, and personnel support. The problem of developing the space and equipment as capital resources available to the sector is not within the scope of the model.

The inputs and outputs are measured in different units. An input of building space, measured in square feet or appropriate modules, produces an output of classroom positions. Total library space, together with books, furnishings, and personnel effort, produces "use-units" of books and study area. The cost of the space or equipment units produced include the cost of maintenance and operation.

The physical resources of the university are conveniently separated into primary facilities and secondary facilities, represented respectively by vectors $\underline{x}(t)$ and $\underline{z}(t)$ whose components are categories of space and equipment. Primary facilities are considered to be utilized directly for academic and non-academic production, or for personnel, while secondary facilities, such as power plants, or storage space, are required for support of primary facilities.

The environmental facilities produced by the Physical Facilities sector are represented by the vector

$$\underline{e}(t) = \begin{bmatrix} \underline{e}_1(t) \\ \underline{e}_2(t) \\ \underline{e}_3(t) \\ \underline{e}_4(t) \end{bmatrix} \begin{array}{l} \text{to Academic Production} \\ \text{to Non-Academic Production} \\ \text{to Personnel} \\ \text{to Administrative Control} \end{array}$$

In general form, the input-output relations of the Physical Facilities sector are

Primary Space $\underline{x}(t) = \Gamma \underline{e}(t)$

Secondary Space $\underline{z}(t) = \Delta \underline{x}(t)$

Labor $\underline{\ell}(t) = \Lambda_1 \underline{x}(t) + \Lambda_2 \underline{z}(t)$

A model identifying the major input-output flows of the Physical Facilities sector is obtained by writing these equations in the form

1:3.3.2a

$$\begin{array}{l} \text{Primary} \\ \text{Secondary} \\ \text{Labor} \end{array} \begin{bmatrix} \underline{x}(t) \\ \underline{z}(t) \\ \underline{\ell}(t) \end{bmatrix} = \begin{bmatrix} \Gamma \\ \Delta\Gamma \\ \Lambda_1\Gamma + \Lambda_2\Delta\Gamma \end{bmatrix} [\underline{e}] \text{ Environmental Facilities}$$

The unit costs of environmental facilities, including the cost of labor required for maintenance and operation and the cost of the required support facilities are

1:3.3.2b

$$\begin{array}{c}\text{Cost of Environmental}\\ \text{Facilities}\end{array} \quad \underline{\hat{e}}(t) = \begin{bmatrix} \Gamma \\ \Delta\Gamma \\ \Lambda_1\Gamma + \Lambda_2\Delta\Gamma \end{bmatrix}^T \begin{bmatrix} \underline{\hat{x}}(t) \\ \underline{\hat{z}}(t) \\ \underline{\hat{\ell}}(t) \end{bmatrix} \begin{array}{l} \left.\vphantom{\begin{array}{c}a\\b\end{array}}\right\} \begin{array}{l}\text{Cost of}\\ \text{Physical}\\ \text{Facilities}\end{array} \\ \left.\vphantom{a}\right\} \begin{array}{l}\text{Cost of}\\ \text{Labor}\end{array} \end{array}$$

Support facilities, such as libraries, computers, and classroom and office buildings, come from capital investments. Thus the physical plant facilities of the university can be viewed as coming from another sector of the university, not explicitly included in the model--a sector that might be referred to as capital resources. The way in which unit costs vary with the size of the university depends in part on how capital costs are allocated and in part on the policies used by the administration in providing capital investments.

The development of a capital resources sector model with inputs from various funding sources and output of major space and equipment units represents an area for future study. Among other things, such a model would account for time lags between planning for and the realization of major new resources. Bowman [15] presents a related model for management of the endowment funds for a private institution.

1:3.4. The System Model

1:3.4.1 Combining the Sector Models

The models developed for the student sector, production sectors, and resource sectors in 1:3.1, 1:3.2 and 1:3.3 are unconstrained models. When the system operates as an integrated unit, constraints are imposed on the flows and unit costs associated with the various component inputs and outputs as implied by the schematic diagram in Fig. 1:2.1-I. The constraints in this system are unusually simple and have, in fact, been implicitly recognized by the use of the same notation for some of the variables in the sector models.

One of the relationships, however, imposes a key constraint on certain variables in the form of a "feedback loop" connecting the student, production, and personnel sectors. In the model of the student sector, the state transition equation, 1:3.1.2a, establishes the student distribution at any time as a function of $\underline{g}(t)$, the number of graduate assistantships awarded. The graduate assistant effort utilized by the system in turn depends upon the student distribution and its induced demand for course credits and other services. An important constraining loop of the system results from the fact that the number of units of graduate assistantships, $\underline{g}(t)$, and the number of units of graduate assistant personnel, $\underline{y}_1(t)$, must be identical.

The state transition equation of the system model is obtained by applying to the variables in 1:3.1.2a the constraints resulting from the "loop" already described. These constraints allow the vector $\underline{g}(t)$ to be written as a function of the state, $\underline{s}(t)$, and the outside services produced, $\underline{o}(t)$. The resulting equation has the form:

1:3.4.1a

$$\underline{s}(t) = \overbrace{B^{-1}P(t)\underline{s}(t-1)}^{\text{Transition of former students}} + \overbrace{B^{-1}\underline{a}(t)n(t)}^{\text{Distribution of new students}} + B^{-1}K_1V_2G_3\overset{\text{outside services}}{\underline{o}(t)} + B^{-1}K_2\overset{\text{fellowships and scholarships}}{\underline{h}(t)} + \dots$$

The matrix B is a composite parameter matrix described in detail in 1:4. Its entries are derived from parameters determined by the student demands for course credits and research teaching, by the policies on utilization of graduate assistants in teaching and other types of production, and, finally, by the influence of graduate assistantships on enrollments.

Clearly, the non-zero entries in B refer almost entirely to the coordinates of the state vector associated with graduate levels. Although the numerical values of all the component parameters contributing to these entries have not been evaluated,. the functional form of the state transition equation gives a mathematical portrayal of a key university management problem. Under a fixed set of operating policies, any increase in outside research $\underline{o}(t)$ or student enrollments $\underline{s}(t)$ results in an increased demand for graduate assistant effort. However, an increase in the number of graduate assistants then results in an increased enrollment and demand for advanced courses and dissertation guidance, implying a further increase in faculty effort. Conversely, in some colleges, particularly Engineering, the graduate enrollment depends very heavily upon the availability of research and teaching assistantships. This interdependence is explicit in the model. Discussion of the state transition equation in forecasting and planning may be found in 2:1.5.

Equation 1:3.4a contains as control factors the vector of fellowships and scholarships $\underline{h}(t)$ and outside services $\underline{o}(t)$ under contracts or grants. Note that the vector $\underline{g}(t)$ of graduate assistantships is a control factor in the same sense, since it depends on demands for services as reflected by the policies followed in the use of graduate assistants in teaching and research. As other factors are isolated which influence enrollments, they will appear as additional control factors in 1:3.4a.

In addition to the state transition equation, the model yields equations for other variables which may be regarded as "responses," --- developed manpower, resource requirements, costs, etc. The output of educated manpower, for example, is

1:3.4.1b $$\underline{d}(t) = D(t)\,\underline{s}(t-1) - B'\,\underline{s}(t) - K_{21}\overset{\text{fellowships and scholarships}}{\underline{h}(t)} - K_{11}V_2G_3\overset{\text{outside services}}{\underline{o}(t)}$$

where the matrix B' is a composite of parameter matrices related to the use of graduate assistants (see 1:4.4).

The required academic personnel is

1:3.4.1c $$\underline{w}_1(t) = B''\overset{\text{student enrollment}}{\underline{s}(t)} + A_1F_3\overset{\text{outside services}}{\underline{o}(t)} + A_3\overset{\text{administrative effort}}{\underline{a}(t)}$$

The matrix B'' is given as a function of the component parameters in 1:4.4. In a similar manner any other flow variable in the system can be expressed as a function of the system states and control variables.

Likewise, the unit cost vectors for any of the variables in the model may also be established. A few examples are presented here.

1:3.4.1d Unit Cost of Outside Services

$$\hat{\underline{o}}(t) = F_3{}^T\hat{\underline{f}}(t) + G_3{}^T\hat{\underline{g}}'(t) + E_3{}^T\underline{e}_1(t)$$

where $\hat{\underline{f}}(t)$, represents the unit costs of faculty effort, and $\hat{\underline{g}}'(t)$ the unit costs of graduate assistant effort, as computed from the Personnel sector, and $\hat{\underline{e}}_1(t)$ represents the unit costs of environmental facilities as computed from the Physical Facilities sector.

1:3.4.1e Unit Cost of Faculty Used in Academic Production

$$\hat{\underline{f}}(t) = A_1{}^T\overset{\text{salary costs}}{\hat{\underline{w}}_1(t)} + A_1{}^TB_1{}^T\overset{\text{cost of office staff}}{\hat{\underline{w}}_2(t)} + [A_1{}^TY_1{}^T + A_1{}^TB_1{}^TY_2{}^T]\overset{\text{cost of environmental facilities}}{\hat{\underline{e}}_3(t)}$$

1:3.4.1f Imputed Unit Values of Education

$$\underline{\hat{s}}(t) = Q(t)\,\underline{\hat{s}}(t-1) + \underline{\hat{a}}(t) - [\,C^T\ R^T\,] \begin{bmatrix} F_1^{\ T} & G_1^{\ T} & E_1^{\ T} \\ F_2^{\ T} & G_2^{\ T} & E_2^{\ T} \end{bmatrix} \begin{bmatrix} \underline{\hat{f}}(t) \\ \underline{\hat{g}}'(t) \\ \underline{\hat{e}}_1(t) \end{bmatrix}$$

(Note: The costs $\underline{\hat{f}}(t)$, $\underline{\hat{g}}'(t)$, and $\underline{\hat{e}}_1(t)$ of faculty effort, graduate assistant effort, and environmental facilities, are computed as negative numbers.)

1:3.4.2 Budget Flows

Since each flow in the model establishes a pair of variables, indicating number of units of flow and unit cost or value, the total cost or value of any flow may be computed as the product of these two variables.

As an example, the total budget for faculty academic services may be determined from the model. The components of the vector $\underline{f}(t)$ denote the required number of units of faculty effort, possibly separated by ranks, for teaching, research, and outside services, in various units of the university. The components of $\underline{\hat{f}}(t)$ indicate average unit costs. The inner product

$$\underline{f}(t) \cdot \underline{\hat{f}}(t) = \sum_i f_i(t)\,\hat{f}_i(t)$$

establishes the total budget. This cost includes the cost of offices and staff needed to support the required academic personnel. On the other hand, the inner product $(\underline{w}_1(t) \cdot \underline{\hat{w}}_1(t))$ establishes the total budget for all academic personnel, including only salaries.

In a similar manner, budgets related to particular operations of the university may be determined from inner products of appropriate sub-vectors of costs and flows. Therefore, the system model serves as a tool for modern budgetary techniques such as the Planning-Programming-Budgeting methods used by the federal government.

A PPB system is a budgeting concept designed to place explicit emphasis on the planning aspect of budgeting, rather than on management or operational control. The roots of PPB lie in Keynesian macro-economics and systems analysis. Its goal is to provide data on the costs and benefits of alternative ways of realizing objectives, with data compiled in such a way that comparisons can be made among alternative expenditure mixes. A "program" is regarded as encompassing the total resource and effort required to achieve a particular "customer-oriented" objective. Under a Program-Planning-Budgeting system, budgeting becomes a decision process at the highest policy-making level, with conscious appraisal of future goals [51, 105].

The establishment of any program budgeting scheme clearly requires the use of a system model which relates resources to outputs and which can be used to simulate the results of alternate aggregations of expenditures.

1:3.4.3 Adding Components to the Model

The form of development of the state model allows components to be added or modified at any time without reorganizing the total model structure. It is clear that any of the flow vectors may be modified to allow for such things as curriculum reorganization, changes in faculty structure, or new student services. The parameter matrices of the sectors, which usually consist of input-output ratios, are then computed on the basis of the newly-defined variables.

To illustrate how a new activity of the university can be added to the model, consider the hypothetical case where a continuing education program is developed. In the model as described in this report the academic and non-academic faculty effort and resources required in such a program are included in the outside services vector $\underline{o}(t)$ as exogenous variables, i.e. variables which are considered as unknown variables in the model (see Fig. 1:2.1-I). However, the continuing education sector can be modeled as another input-output component having the appropriate components of $\underline{o}(t)$ as inputs and having as outputs a series of educational services for industrial professional and other groups outside the university community. The demand for such services might be expressed as a function of various segments of the population. Consequently, under these conditions some of the components of $\underline{o}(t)$ are no longer specified exogenously -- they are given as a function of other variables through the added model of the continuing education sector.

As already discussed in 1:3. 3. 2 a model of capital resource formation can be coupled to the existing model by constraining the input resources to the existing model to be equal to the output of the capital resources sector.

In a similar manner the model of the university as given here can be regarded as a component of a larger system. One such potential application is discussed in 1:5.

1:4 The Mathematical Model

1:4.1 Index to Variables Used in the Report (all variables are associated with a given time period t)

$\underline{a}(t)$ $n(t)$	vector of students by field and level entering at the beginning of the time period.
$\hat{\underline{a}}(t)$	vector of imputed values of entering students
$\underline{\alpha}(t)$	vector of staff effort required for administration
$\hat{\underline{\alpha}}(t)$	imputed values of $\underline{\alpha}(t)$
$\underline{c}(t)$	vector of student credits demanded by student population within the institution
$\hat{\underline{c}}(t)$	average costs per unit of $\underline{c}(t)$
$\underline{d}(t)$	vector of students by field and level leaving the institution during or at the end of the time period.
$\hat{\underline{d}}(t)$	imputed values of $\underline{d}(t)$ based on cumulative cost of education
$\underline{en}(t)$	vector of number of students enrolled in courses or research-teaching
$\underline{e}(t)$	vector of support facilities by types required by production sectors
$\hat{\underline{e}}(t)$	average costs per unit of $\underline{e}(t)$
$\underline{f}(t)$	vector of required faculty academic effort, by rank and field
$\hat{\underline{f}}(t)$	average costs per unit of $\underline{f}(t)$
$\underline{g}(t)$	vector of graduate assistantships, by field
$\underline{g}'(t)$	vector of graduate assistant effort
$\hat{\underline{g}}'(t)$	average costs per unit of $\underline{g}'(t)$
$\underline{h}(t)$	vector of fellowships and scholarships
$\hat{\underline{h}}(t)$	average unit values of $\underline{h}(t)$
$\underline{k}(t)$	vector of staff effort required for non-academic student services

$\hat{\underline{k}}(t)$	average costs per unit of $\underline{k}(t)$
$\underline{\ell}(t)$	vector of employee effort required for operation and maintenance of plant and equipment
$\hat{\underline{\ell}}(t)$	average costs per unit of $\underline{\ell}(t)$
$\underline{m}(t)$	vector of required medical and social services
$\hat{\underline{m}}(t)$	average costs per unit of $\underline{m}(t)$
$\underline{n}(t)$	gross number of new students entering at beginning of time period
$\hat{\underline{n}}(t)$	imputed unit values of past education of new freshmen
$\underline{o}(t)$	vector of contracted outside services by type
$\hat{\underline{o}}(t)$	imputed values of $\underline{o}(t)$
$\underline{p}(t)$	vector of required services for processing, registration, evaluation, etc.
$\hat{\underline{p}}(t)$	average costs per unit of $\underline{p}(t)$
$\underline{r}(t)$	vector of research-teaching credits demanded by the student population
$\hat{\underline{r}}(t)$	average costs per unit of $\underline{r}(t)$
$\underline{\mathfrak{r}}(t)$	vector of required residential and food services
$\hat{\underline{\mathfrak{r}}}(t)$	average costs per unit of $\underline{r}(t)$
$\underline{s}(t)$	vector of student populations by field and level
$\hat{\underline{s}}(t)$	imputed values of $\underline{s}(t)$ based on cost of education received
$\underline{u}(t)$	vector of usage-units of environmental facilities in academic production
$\underline{w}(t)$	vector of required academic staff
$\hat{\underline{w}}(t)$	average unit costs of $\underline{w}(t)$
$\underline{x}(t)$	vector of required primary physical facilities
$\hat{\underline{x}}(t)$	average unit costs of $\underline{x}(t)$
$\underline{y}(t)$	vector of required student employees

$\hat{\underline{y}}(t)$	average unit costs of $\underline{y}(t)$
$\underline{z}(t)$	vector of required secondary physical facilities
$\hat{\underline{z}}(t)$	average unit costs of $\underline{z}(t)$

1:4.2 Index to Parameter Matrices Used in the Report

A_1, A_3, A_5	Parameter matrices of the personnel sector whose entries represent equivalent full time academic personnel per unit of academic, administrative, and student service effort respectively.
B_1, B_4, B_5	Parameter matrices of the personnel sector whose entries represent equivalent full-time non-academic staff per academic staff member and per unit of technical and student service effort.
C	Demand matrix of the student sector whose entries represent average course credits per student.
D(t)	Behavioral matrix of the student sector of diagonal form whose entries represent proportions of departing students during or at the end of time period t.
E_1, E_2, E_3	Policy matrices of the academic production sector whose entries represent units of environmental facilities per unit of course credits, research teaching, or outside services.
E_1', E_2', E_3'	Policy matrices of the student service (non-academic production) sector whose entries represent units of environmental facilities per unit of service provided.
EN	Behavioral matrix whose entries represent average course selection by students in each category.
F_1, F_2, F_3	Policy matrices of the academic production sector whose entries represent equivalent full-time faculty academic effort per student credit of course work or research-teaching or per unit of outside services.

G_1, G_2, G_3	Policy matrices of the academic production sector whose entries represent equivalent full-time graduate assistant academic effort per student credit of course work or research teaching, or per unit of outside services.
K_{11}	Behavioral matrix of the student sector representing the relative effectiveness of assistantships in inducing students to remain in the university. The entries represent students retained per assistantship.
K_{12}	Behavioral matrix of the student sector representing the relative effectiveness of assistantships in attracting new students. The entries represent students attracted per assistantship.
$K_1 = K_{11} + K_{12}$	
K_{21}, K_{22}	Behavioral matrices of the student sector representing the influence of fellowships and scholarships. Similar to K_{11} and K_{12}.
$K_2 = K_{21} + K_{22}$	
M_1, M_2, M_3	Demand matrices of the student services (non-academic production) sector whose entries represent units of services demanded per student.
$Q(t)$	Matrix used in the student sector in iterated computation of attributed accumulated value of education received by students. Entries indicate the proportion of students of category i who transferred from category j, $i = 1, .., N$; $j = 1, .., N$.
R	Demand matrix of the student sector whose entries represent average research-teaching credits per student.
U	Policy matrix of academic production sector whose entries represent average usage per week of various support facilities.
U_4, U_5	Policy matrices of the personnel sector whose entries represent equivalent full-time employees per unit of maintenance and student service effort.
V_2, V_5	Policy matrices of the personnel sector whose entries represent equivalent full-time graduate assistants per unit of academic and student service effort.

W_4, W_5	Policy matrices of the personnel sector whose entries represent equivalent full-time student hourly employees per unit of maintenance and student service effort.
Y_1, Y_2, Y_3	Policy matrices of the personnel sector whose entries represent units of environmental facilities per full-time equivalent academic staff, non-academic staff, and graduate assistant.
Γ	Policy matrix of the Physical facilities sector whose entries represent units of primary plant or equipment per unit of environmental facilities.
Δ	Policy matrix of the Physical facilities sector whose entries represent units of secondary facilities per unit of primary plant or equipment.
$\theta_1, \theta_2, \theta_3$	Policy matrices of the student service (non-academic production) sector whose entries represent units of staff effort per unit of service.
Λ_1, Λ_2	Policy matrices of the Physical facilities sector whose entries represent units of labor per unit of primary and secondary facilities.

1:4.3 The Sector Models (Summary)

Student Sector

1:4.3a State transition equation

$$\underline{s}(t) = P(t)\,\underline{s}(t-1) + \underline{a}(t)\,n(t) + K_1\,\underline{g}(t) + K_2\,\underline{h}(t) + \ldots$$

1:4.3b Output of educated manpower

$$\underline{d}(t) = D(t)\,\underline{s}(t-1) - K_{11}\,\underline{g}(t) - K_{21}\,\underline{h}(t) \ldots\ldots$$

1:4.3c Student Demands

$$\begin{bmatrix} \underline{c}(t) \\ \underline{r}(t) \end{bmatrix} = \begin{bmatrix} C \\ R \end{bmatrix} \quad \underline{s}(t)$$

1:4.3d Imputed value of education received

$$\hat{\underline{s}}(t) = Q(t)\,\hat{\underline{s}}(t-1) - \hat{\underline{a}}(t) - c^T\,\hat{c}(t) - R^T\,\hat{\underline{r}}(t)$$

$$[Q(t)] = [q_{ij}] \quad \text{where } q_{ij} = \frac{p_{ij}(t)\; s_i(t-1)}{s_i(t)}$$

$$\hat{\underline{a}}(t) = [\hat{a}_1(t), \ldots, \hat{a}_n(t)]^T \quad \text{where}$$

$$\hat{a}_i(t) = \frac{a_i(t)\; n(t)}{s_i(t)}\; \hat{s}_i(t-1)\,.$$

The value of $\hat{\underline{s}}(t)$ is negative since it is cost of output produced. $\hat{\underline{c}}(t)$ and $\hat{r}(t)$ are positive since they are values of resources used.

Academic Production Sector:

1:4.3e Production

$$\begin{bmatrix} \underline{f}(t) \\ \underline{g}'(t) \\ \underline{e}_1(t) \end{bmatrix} = \begin{bmatrix} F_1 & F_2 & F_3 \\ G_1 & G_2 & G_3 \\ E_1 & E_2 & E_3 \end{bmatrix} \begin{bmatrix} \underline{c}(t) \\ \underline{r}(t) \\ \underline{o}(t) \end{bmatrix}$$

1:4.3f Cost of Production

$$\begin{bmatrix} \hat{\underline{c}}(t) \\ \hat{\underline{r}}(t) \\ \hat{\underline{o}}(t) \end{bmatrix} = - \begin{bmatrix} F_1 & F_2 & F_3 \\ G_1 & G_2 & G_3 \\ E_1 & E_2 & E_3 \end{bmatrix}^T \begin{bmatrix} \hat{\underline{f}}(t) \\ \hat{\underline{g}}'(t) \\ \hat{\underline{e}}_1(t) \end{bmatrix}$$

These costs are negative since they are costs of outputs produced.

1:4.3g Computation of environmental resources based on enrollments

$$\underline{e}_1(t) = [E' \quad E_3] \begin{bmatrix} \underline{u}(t) \\ \underline{o}(t) \end{bmatrix}$$

$$\underline{u}(t) = U\,\underline{en}(t) = U\,EN\,\underline{s}(t)$$

Student Services (Non-academic Production Sector)

1:4.3h Student demands

$$\begin{bmatrix} \underline{p}(t) \\ \underline{r}(t) \\ \underline{m}(t) \end{bmatrix} = \begin{bmatrix} M_1 \\ M_2 \\ M_3 \end{bmatrix} \underline{s}(t)$$

1:4.3i Production

$$\begin{bmatrix} \underline{k}(t) \\ \underline{e}_2(t) \end{bmatrix} = \begin{bmatrix} \theta_1 & \theta_2 & \theta_3 \\ E_1' & E_2' & E_3' \end{bmatrix} \begin{bmatrix} \underline{p}(t) \\ \underline{r}(t) \\ \underline{m}(t) \end{bmatrix}$$

1:4.3j Cost of Services

$$\begin{bmatrix} \hat{\underline{p}}(t) \\ \hat{\underline{r}}(t) \\ \hat{\underline{m}}(t) \end{bmatrix} = \begin{bmatrix} \theta_1 & \theta_2 & \theta_3 \\ E_1' & E_2' & E_3' \end{bmatrix}^T \begin{bmatrix} \hat{\underline{k}}(t) \\ \hat{\underline{e}}_2(t) \end{bmatrix}$$

Personnel Resources

1:4.3k Production Equations:

$$\underline{w}_1(t) = A_1\underline{f}(t) + A_3\,\underline{a}(t) + A_5\underline{k}(t)$$

$$\underline{w}_2(t) = B_1\underline{w}_1(t) + B_4\underline{\ell}(t) + B_5\underline{k}(t)$$

$$\underline{w}_3(t) = U_4\underline{\ell}(t) + B_5\,\underline{k}(t)$$

$$\underline{y}_1(t) = V_2\,\underline{g}'(t) + V_5\,\underline{k}(t)$$

$$\underline{y}_2(t) = W_4\,\underline{\ell}(t) + W_5\,\underline{k}(t)$$

$$\underline{e}_3(t) = Y_1\,\underline{w}_1(t) + Y_2\,\underline{w}_2(t) + Y_3\,\underline{y}_1(t)$$

1:4. 3ℓ Sector Model

$$\begin{bmatrix} \underline{w}(t) \\ \\ \underline{y}(t) \end{bmatrix} = \begin{bmatrix} \underline{w}_1(t) \\ \underline{w}_2(t) \\ \underline{w}_3(t) \\ \hdashline \underline{y}_1(t) \\ \underline{y}_2(t) \end{bmatrix} = \begin{bmatrix} A_1 & 0 & A_3 & 0 & A_5 \\ B_1A_1 & 0 & B_1A_3 & B_4 & B_1A_5+B_5 \\ 0 & 0 & 0 & U_4 & U_5 \\ 0 & V_2 & 0 & 0 & V_5 \\ 0 & 0 & 0 & W_4 & W_5 \end{bmatrix} \begin{bmatrix} \underline{f}(t) \\ \underline{g}'(t) \\ \underline{a}(t) \\ \underline{\ell}(t) \\ \underline{k}(t) \end{bmatrix}$$

$$[\underline{e}_3(t)] = [\, Y_1 \mid Y_2 \mid Y_3] \begin{bmatrix} A_1 & 0 & A_3 & 0 & A_5 \\ B_1A_1 & 0 & B_1A_3 & B_4 & B_1A_5+B_5 \\ 0 & V_2 & 0 & 0 & V_5 \end{bmatrix} \begin{bmatrix} \underline{f}(t) \\ \underline{g}'(t) \\ \underline{a}(t) \\ \underline{\ell}(t) \\ \underline{k}(t) \end{bmatrix}$$

1:4. 3m Cost of production

$$\begin{bmatrix} \hat{\underline{f}}(t) \\ \hat{\underline{g}}'(t) \\ \hat{\underline{a}}(t) \\ \hat{\underline{\ell}}(t) \\ \hat{\underline{k}}(t) \end{bmatrix} = - [\mathcal{A}^T \mid \mathcal{D}^T \; \mathcal{B}^T] \begin{bmatrix} \hat{\underline{w}}(t) \\ \hat{\underline{y}}(t) \\ \hat{\underline{e}}_3(t) \end{bmatrix}$$

where

$$\mathcal{A}^T = \begin{bmatrix} A_1 & 0 & A_3 & 0 & A_5 \\ B_1A_1 & 0 & B_1A_3 & B_4 & B_1A_5+B_5 \\ 0 & 0 & 0 & U_5 & U_5 \\ 0 & V_2 & 0 & 0 & V_5 \\ 0 & 0 & 0 & W_4 & W_5 \end{bmatrix}$$

and

$$\mathcal{A}^T \mathcal{B}^T = \begin{bmatrix} A_1 & 0 & A_3 & 0 & A_5 \\ B_1A_1 & 0 & B_1A_3 & B_4 & B_1A_5+B_5 \\ 0 & V_2 & 0 & 0 & V_5 \end{bmatrix}^T \quad [Y_1 \,\vdots\, Y_2 \,\vdots\, Y_3]^T$$

Physical Facility Resources

1:4. 3n Production equations

$$\underline{x}(t) = \Gamma \underline{e}(t)$$

$$\underline{z}(t) = \Delta \, \underline{x}(t)$$

$$\underline{\ell}(t) = \Lambda_1 \, \underline{x}(t) + \Lambda_2 \, \underline{z}(t)$$

1:4. 3o Sector Model

$$\begin{matrix} \underline{x}(t) \\ \underline{z}(t) \\ \underline{\ell}(t) \end{matrix} = \begin{bmatrix} \Gamma \\ \Delta\Gamma \\ \Lambda_1\Gamma + \Lambda_2 \, \Delta\Gamma \end{bmatrix} [\underline{e}]$$

1:4. 3p Cost of Production

$$\hat{\underline{e}}(t) = \begin{bmatrix} \Gamma \\ \Delta\Gamma \\ \Lambda_1\Gamma + \Lambda_2 \, \Delta\Gamma \end{bmatrix}^T \begin{bmatrix} \hat{\underline{x}}(t) \\ \hat{\underline{z}}(t) \\ \hat{\underline{\ell}}(t) \end{bmatrix}$$

1:4.4 The System Model (summary)

1:4.4a State transition equation

$$\underline{s}(t) = \overbrace{B^{-1}P(t)\,\underline{s}(t-1)}^{\text{Transition of former students}} + \overbrace{B^{-1}\,\underline{a}(t)\,n(t)}^{\text{Distribution of new students}} + B^{-1}\,K_1V_2G_3\,\overset{\text{outside services}}{\underline{o}}(t) + B^{-1}\,K_2\,\overset{\text{fellowships and scholarships}}{\underline{h}}(t) + \ldots$$

$$B = [I - K_1V_2G_1C - K_1V_2G_2R - K_1V_5\theta_1M_1 - K_1V_5\theta_2M_2 - K_1V_5\theta_3M_3].$$

1:4.4b Manpower output

$$\underline{d}(t) = D(t)\,\underline{s}(t-1) - B'\,\underline{s}(t) - K_{21}\,\overset{\text{fellowships and scholarships}}{\underline{h}}(t) - K_{11}V_2\,G_3\,\overset{\text{outside services}}{\underline{o}}(t)$$

where

$$B' = [K_{11}V_2G_1C + K_{11}V_2G_2R + K_{11}V_5\theta_1M_1 + K_{11}V_5\theta_2M_2 + K_{11}V_5\theta_3M_3].$$

1:4.4c Required academic personnel

$$\underline{w}_1(t) = B''\,\underline{s}(t) + A_1F_3\,\overset{\text{outside services}}{\underline{o}}(t) + A_3\,\overset{\text{administrative effort}}{\alpha}(t)$$

where

$$B'' = [A_1F_1C + A_1F_2R + A_5\,\theta_1M_1 + A_5\theta_2M_2 + A_5\theta_3M_3].$$

1:4.4d Unit cost of outside services

$$\hat{\underline{o}}(t) = F_3^{\,T}\,\hat{\underline{f}}(t) + G_3^{\,T}\,\hat{\underline{g}}'(t) + E_3^{\,T}\,\hat{\underline{e}}_1(t)$$

1:4.4e Unit cost of faculty in academic production

$$\underline{\hat{f}}(t) = \overset{\text{salary costs}}{A_1^T \underline{\hat{w}}_1(t)} + \overset{\text{cost of office staff}}{A_1^T B_1^T \underline{\hat{w}}_2(t)} + [A_1^T Y_1^T + A_1^T B_1^T Y_2^T] \overset{\text{cost of environmental facilities}}{\underline{\hat{e}}_3(t)}$$

1:4.4f Imputed unit accumulated value of education

$$\underline{\hat{s}}(t) = Q(t)\, \underline{\hat{s}}(t-1) + \underline{\hat{a}}(t) - [C^T \; R^T] \begin{bmatrix} F_1^T & G_1^T & E_1^T \\ F_2^T & G_2^T & E_2^T \end{bmatrix} \begin{bmatrix} \underline{\hat{f}}(t) \\ \underline{\hat{g}}'(t) \\ \underline{\hat{e}}_1(t) \end{bmatrix}$$

1:4.5 The Mathematics of Control

It is not the purpose here to enter into a discussion or even a survey of optimal control theory and its application to the problems discussed here. Entire books are devoted to this subject [10, 121]. It is sufficient to say that to the extent that the computation problems involved in actually evaluating optimal control strategies are feasible for institutions of higher education, the literature on the subject can be applied directly.

The state model of an educational institution given in 1:4.4 is a special case of the general form:

1:4.5a $$\underline{\Psi}(t+1) = F_1[\underline{\Psi}(t), \underline{q}(t), \underline{u}(t)], \quad \Psi(t_1) = \Psi_1$$

1:4.5b $$\underline{v}(t) = F_2(\underline{\Psi}, \underline{q}, \underline{u}, t)$$

where

$\Psi(t)$ represents the state vector identified in the model, and

$\Psi(t_1) = \Psi_1$ represents the initial state

$\underline{q}$ is a vector of identified policy or production parameters, called control parameters, to be varied over some space Q

$\underline{u}$ is a vector of identified variables, called input controls, variable over some space U

$\underline{v}$ is a vector of identified outputs or response variables of interest

F_1 and F_2 are vector functions of the indicated vectors and the scalar t.

The system in equations 1:4.5a and 1:4.5b is said to be state controllable if there exist vectors $\underline{u}$ and/or $\underline{q}$ which will transfer any given state $\underline{\Psi}_1$ to a preassigned future state $\underline{\Psi}_2$ in a finite number of time intervals. It is said to be output controllable if any given output vector $\underline{v}_1$ can be transferred to a preassigned future value $\underline{v}_2$ in a finite number of time intervals. It is easy to establish that state controllability implies output controllability but not vice versa. Indeed, the output vector may contain fewer components than the state vector.

Applying these concepts to the model of an educational institution given in 1:4.4, it is seen that the state vector is the direct sum of the student population vector $\underline{s}$ and the vector of imputed values $\hat{\underline{s}}$. However, from equations 1:4.4a and 1:4.4f it can also be seen that $\underline{s}(t)$ is a function of the financial aid vector $\underline{h}(t)$ and the outside services $\underline{o}(t)$, whereas $\hat{\underline{s}}(t)$ is not. Consequently, the system is clearly not state controllable with respect to $\underline{h}(t)$ and $\underline{o}(t)$. However, one can select as outputs

$$\underline{v}(t) = [I\ 0] \begin{bmatrix} \underline{s}(t) \\ \hat{\underline{s}}(t) \end{bmatrix}$$

where I is the identity matrix, and investigate further the output controllability of the system as a very meaningful question. Indeed, if

$$A = (P + K_1 G_1 C + K_1 G_2 R)$$
$$B = [K_1 G_3 K_2 \underline{a}]$$
$$\underline{u} = [\underline{o}\ \underline{h}\ \underline{n}]$$

and all parameter matrices are assumed to be independent of time, then 1:4.4a takes on the form

1:4.5c $$\underline{s}(t) = A\ \underline{s}(t-1) + B\ \underline{u}(t)$$

Applying equation 1:4.5c recursively for k intervals of time beginning at $t = t_1$ gives

1:4.5d $$\underline{s}(t_1 + k) = A_k s(t_1) + [A^{k-1}B \ldots AB\ B] \begin{bmatrix} \underline{u}(t_1) \\ u(t_1+1) \\ \cdot \\ \cdot \\ \cdot \\ \underline{u}(t_1+k-1) \end{bmatrix}$$

If the matrix $\phi = [A^{k-1}B \ldots AB\ B]$ is square and non-singular, then for given values of $\underline{s}(t_1+k)$ and $\underline{s}(t_1)$, 1:4.5d has a solution for the control vector

$$\underline{u}_k = [\underline{u}(t_1)\ \underline{u}(t_1 + 1) \dots \underline{u}(t_1 + k-1]^T$$

If the solution exists, the system is said to be output controllable with the control law or control strategy given as a function of the state vector by

1:4.5e $$\underline{u}_k = \phi^{-1} [\underline{s}(t_1 + k) - A^k \underline{s}(t_1)] .$$

Note that $A^k \underline{s}(t)$ represents the solution to 1:4.5c after k intervals when $\underline{u}(t) = 0$. Consequently, the bracketed term in 1:4.5e represents the difference between the desired future state and the state that would be obtained in the absence of control, i.e., the free system error state.

If the institution, for example, has no outside services $\underline{o}$, or financial aid programs $\underline{h}$, then $\underline{u}(t) = n(t)$ is a scalar. In this special case $\underline{u}_k$ is of order k, B is a column vector. If the vector $\underline{s}$ identifies k internal states (population groups) then ϕ is a square matrix of order k whose columns may, or may not, be linearly independent depending upon the properties of the matrices A^j, $j=0, \dots, k-1$ and the behavioral vector $\underline{a}$. But even if a solution does exist the resulting inputs $n(t_1)$, $n(t_1 + 1) \dots n(t + k-1)$ required for control may not be feasible. Indeed, some may be negative.

A somewhat less academic problem arises in the context of most state-supported institutions where the student input n(t) is determined by an essentially open door policy and cannot be regarded as a control variable. To the extent that the given model is valid, such institutions must rely on such variables as outside services $\underline{o}$ and financial aid $\underline{h}$ to control the distribution of students among the various fields and levels of study identified by the vector s. If there are a total of ℓ such components of control in $\underline{u}(t)$, then $\underline{u}_k = [\underline{u}(t_1), \ldots, \underline{u}(t_1 + k-1)]^T$ is of order $k\ell$ and the coefficient matrix ϕ is square when $\underline{s}$ is of order $k\ell$. Again the existence of a solution, and the feasibility of this solution depends entirely upon the behavioral and administrative parameters that combine to form the matrices A and B.

The problem of determining the parameter vector $\underline{q}$ required to transfer the system from one state to another is somewhat more complex since the state equations are almost always a nonlinear function of the components of $\underline{q}$.

In any application of practical interest there are invariably bounds on the values that the components of the control and parameter vectors can assume. The bounds on the control vectors are a consequence of limited funds for financial aid to the students and limited funds for research, etc. The bounds on the components of the parameter vector, such as student to faculty ratios and graduate assistant to faculty ratios, are imposed by judgments on quality of education.

Within the context of these very real constraints one can only search for the time sequence of parameters $\underline{q}(t)$ and controls $\underline{u}(t)$ that will take the system to a prescribed state in a given time period. These control problems fall within a class of optimal control problems realized by first defining a scalar *object* function of the state vector, the control vector and the parameter vector of the general form

$$J = G\left[\underline{u}(t_1 + k)\right] + \sum_{t_1}^{t_1+k} H\left[\underline{u}(t), \underline{q}(t), \underline{v}(t), t\right] \tag{1:4.5f}$$

The optimal control problem can now be stated as: minimize J in 1:4.5f subject to the constraints that $\underline{u}(t)$ satisfies 1:4.5c and 1:4.5d and that $\underline{u}(t)$ and $\underline{q}(t)$ are within the admissible sets U and Q respectively. Note that the optimal control problems already cited are special cases of this general problem.

Since the components of the output vector $\underline{v}(t)$ and control vector $\underline{u}(t)$ span all flow streams in and out of the institution and their associated unit values or prices, the object function J in 1:4.5f can obviously be defined so as to represent the total cost of education, the total cost of control, or a weighted combination of these cost functions as evaluated over the k time periods of control.

An alternate and less satisfactory, but perhaps a more practical approach to the control problem,is through simulation, i. e., program the solution of the system model on a computer in such a way that the user can conveniently evaluate the consequences of many alternate control policies in a search for the "best." Such a procedure, of course, may never lead to the optimum solution, but it will in general lead to a solution that represents the best out of the set of meaningful policies and controls that the administrator considers to be worthy of consideration. Such a procedure does not lead to a control strategy* that can be implemented as "on-line" control of the educational system.

1:4.6 Computational Method for Introducing Control Parameters

The student transition equation presented in 1:3.1.1 has the form

1:4.6a $$s(t) = P(t)\,\underline{s}(t-1) + \underline{a}(t)\,n(t).$$

In this equation, $n(t)$ is the total number of new students entering the university at a time t. The vector $\underline{a}(t)$ gives the proportions of new students entering each category, and the matrix $P(t)$ has entries representing proportions of transition (see 1:3.1.1).

In 1:3.1.2, this equation has been adjusted to account for the influence of control variables and has the form

1:4.6b $$\underline{s}(t) = P(t)\,\underline{s}(t-1) + \underline{a}(t)\,n(t) + K_1\,\underline{g}(t) + K_2\,\underline{h}(t).$$

In order to make this adjustment, values must be established for entries in the matrices K_1 and K_2, describing the "unit influence" of the controls, which in this case are financial aids. These matrices are sums

$$K_i = K_{i1} + K_{i2},\ i = 1,\ 2$$

---

* Recall that in control strategy the controls $\underline{q}$ and $\underline{u}$ are known as explicit function of the system states.

where K_{i1} represents influence on student transitions and K_{i2} represents influence on new enrollment. Since the two terms $K_{12}\underline{g}(t)$ and $K_{22}\underline{h}(t)$ represent new enrollment, the term n(t) must denote only the number of new students whose arrival cannot be attributed to the influence of control variables; $\underline{a}(t)$ must represent the distribution of these students. Similarly, P(t) must represent only transitions which cannot be attributed to the influence of controls, since K_{11} $\underline{g}(t)$ and $K_{21}\underline{h}(t)$ represent the portion of the transition induced by the control variables.

The method of parameter computation described here is based on the known number of assistantships, fellowships, and scholarships operative during a given time period t and a study of the "influence" they have had on period t enrollments. The same method can be used to compute the coefficient parameters for any control variables or other influence factors introduced into the model. In this discussion, the unadjusted number of new students is represented by $\tilde{n}(t)$, and entries in the unadjusted transition matrix and new student distribution vector are represented by $\tilde{P}_{ij}(t)$ and $\tilde{a}_i(t)$.

The influence on enrollments is described by the following numbers:

$\alpha_{ij}(\ell)$: The proportion of the transition from category j to category i, from periods (t-1) to t, which is attributed to graduate assistantship aid in classification ℓ during period t; i, j = 1, . . . , N; ℓ = 1, . . . , G. This proportion is based on the average probability of students not making the transition without the aid

$\alpha_{io}(\ell)$: the proportion of new enrollment in category i attributed to graduate assistantship aid in classification ℓ.

$\beta_{ij}(m)$: Corresponding values for classifications of scholarships and

$\beta_{io}(m)$: fellowship aid, $m = 1, \ldots, H$.

Similar pairs of values may be established for any control variables to be included in the model.

Let $g_\ell(t)$ be a coordinate of $\underline{g}(t)$ and let $h_m(t)$ be a coordinate of $\underline{h}(t)$.

The entries of K_{11}, K_{12}, K_{21}, and K_{22} are:

$$k_{i\ell}^{(11)} = \frac{1}{g_\ell(t)} \sum_{j=1}^{N} \alpha_{ij}(\ell)\, \tilde{p}_{ij}(t)\, s_j(t-1)$$

$$k_{i\ell}^{(12)} = \frac{1}{g_\ell(t)} \left[\alpha_{io}(\ell)\, \tilde{a}_i(t)\, \tilde{n}(t) \right]$$

$$k_{im}^{(21)} = \frac{1}{h_m(t)} \sum_{j=1}^{N} \beta_{ij}(m)\, \tilde{p}_{ij}(t)\, s_j(t-1)$$

$$k_{im}^{(22)} = \frac{1}{h_m(t)} \left[\beta_{io}(m)\, \tilde{a}_i(t)\, \tilde{n}(t) \right]$$

Equation 1:4. 6a may now be adjusted to the form 1:4. 6b. Let

$$p_{ij}(t) = \left[1 - \sum_{\ell=1}^{G} \alpha_{ij}(\ell) - \sum_{m=1}^{H} \beta_{ij}(m) \right] \tilde{p}_{ij}(t) .$$

The entries of the adjusted transition matrix P(t) are the terms $p_{ij}(t)$, $i, j = 1, \ldots, N$.

To adjust the equation for new student distribution, first let

$$a_i'(t) = [1 - \sum_{\ell=1}^{G} \alpha_{io}(\ell) - \sum_{m=1}^{H} \beta_{io}(m)] \tilde{a}_i(t)$$

The adjusted number of new students is

$$n(t) = \tilde{n}(t) \sum_{i=1}^{N} a_i'(t) .$$

The adjusted coordinates of the new-student distribution vector are

$$a_i(t) = a_i'(t) / \sum_{i=1}^{N} a_i'(t) .$$

The number n(t) now gives the estimated number of new students, assuming that no controls were used.

The total number of students in category i during time period t is

1:4.6c $$s_i(t) = \sum_{j=1}^{N} p_{ij}(t) s_j(t-1) + a_i(t) n(t) + \sum_{\ell=1}^{G} [k_{i\ell}^{(11)} + k_{i\ell}^{(12)}] g_\ell(t) + \sum_{m=1}^{H} [k_{im}^{(21)} + k_{im}^{(22)}] h_m(t) .$$

In equation 1:4.6c, the sum

$$\sum_{\ell=1}^{G} k_{i\ell}^{(12)} g_\ell(t) + \sum_{m=1}^{H} k_{im}^{(22)} h_m(t)$$

is the new enrollment attributed to the influence of controls. The sum

$$\sum_{\ell=1}^{G} k_{i\ell}^{(11)} g_\ell(t) + \sum_{m=1}^{H} k_{im}^{(21)} h_m(t)$$

is the portion of returning students in $s_i(t)$ whose presence is attributed to the controls.

Computation problems which arise when equation 1:4.6b is used for prediction of enrollments are discussed in 2:1.5.

1:5 Education in the National Economy

1:5.1 The Model as a Description of an Educational System

The model presented in this report is sufficiently general in concept to serve as a model for a set of institutions of higher education operating in parallel and, with further generalization, as a model for an educational system.

When several universities are to be modeled as a system of higher education, the fields and levels used to define the categories of the student vector $\underline{s}(t)$, the classifications of course credits $\underline{c}(t)$, and the various types of resources, must be broad enough to apply to all the institutions of the group.

In keeping with the method used to develop a model of a single institution, each university is first modeled as an independent component of the higher education system. Variables may be arbitrarily defined, so long as it is possible to aggregate them subsequently into categories and classifications common to the entire set. Moreover, each variable is indexed according to a particular university.

When the components are combined, each category of the system state vector $\underline{s}(t)$ identifies a segment of the student population according to field, level, and university. The transition matrix P(t) thus identifies movement between schools as well as progress through the system. Academic production units (see 1:3.2.1) may be aggregated to show the resource requirements by field for the entire student population.

Each institution of the system yields separate estimates of the parameters of the model. From this collection of estimates, an empirical distribution may be derived for each of the parameters. The mean values may then be used in the state model representing the aggregate of all institutions of higher education. In addition, the distribution of values offers useful information concerning such things as the variability in the cost of educating an individual for a particular occupation.

When the model is used to describe the total educational system, rather than higher education alone, all variables must be redefined to encompass the levels and types of education available. The categories, for example, would include primary, secondary, vocational and higher education. Again, this model can be developed from a compatible set of independent models of separate institutions or systems. Such a model can, in turn, serve as a component of a model of the manpower sector of the national economy.

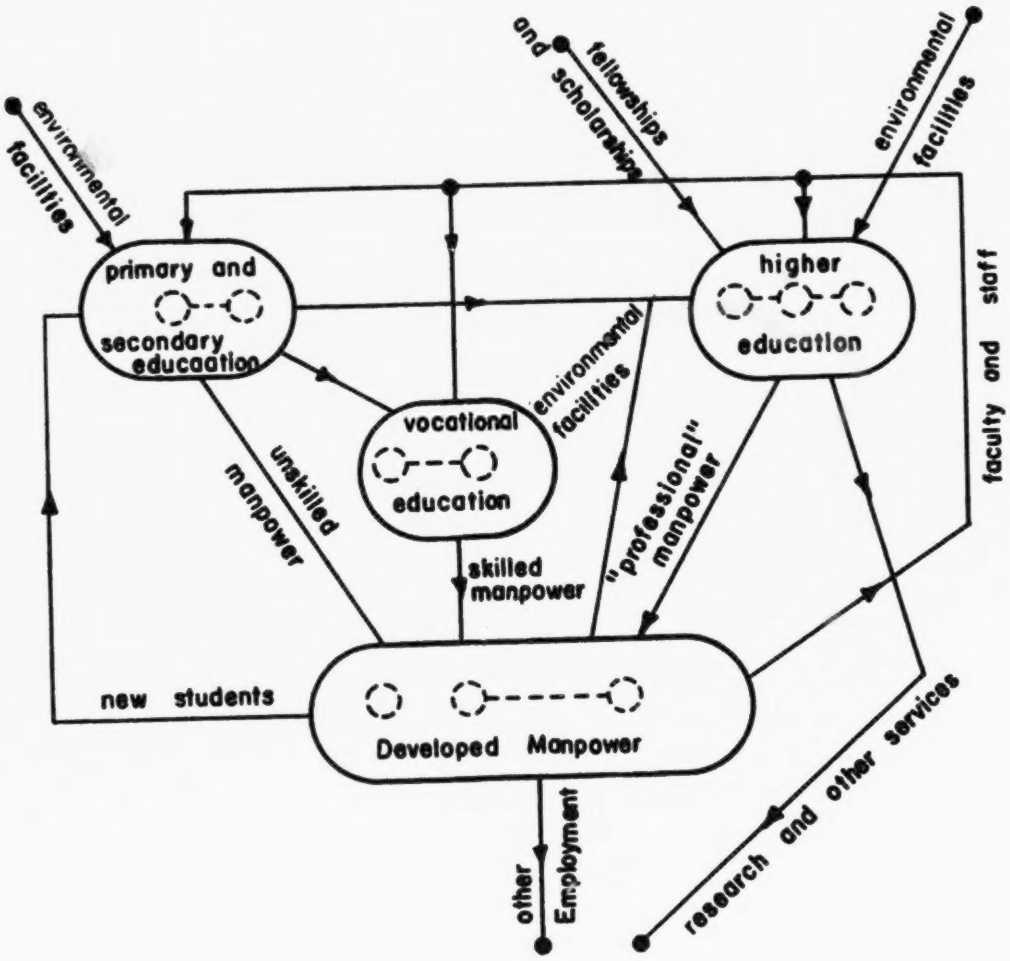
1:5.2 The Educational System as a Component of the National Economy

The position of the various educational institutions in the national economy can be viewed as shown in Figure 1:5.2-I. A stream of students, originating as children born to the population in the various manpower pools, enters the sequential stages of the educational system at the primary level. The educational system is viewed as a production or processing stage taking faculty and other input resources to transform the student input stream into a more highly developed "product." The faculty and support staff required in this process, of course, comes from the manpower pools, thereby forming a second basic circular path of feedback loop in the system.

The manpower pools also serve as the source of manpower in the industrial and government sector (the rest of the economy) required to produce the goods and services consumed by the population pools. The stream of consumer goods feeding back to the manpower sector, of course, may be viewed as containing many components, and one can easily consider "imports" and "exports" from the various flow streams to account for exchanges between neighboring economic systems.

In general, each flow variable is conceived of as being measured in real units per interval of time or in terms of its dollar value as measured by the price structure of an arbitrarily selected base. Also, associated with each stream is a variable representing the economic value, cost or price index of each unit of flow in the identified streams. The variation in these complementary variables with time for all streams in the system is said to completely characterize the socio-economic process. The product of the flow and unit value variables represents the dollar flow rate for each stream.

In considering the educational system as a component of the national economy, the output $\underline{d}(t)$ of students from each level of education, in each area of study, is assumed to feed into a manpower sector of the population, whose categories may be represented by a vector $\underline{m}(t)$. The categories include all types of employment in the economy, from unskilled through professional. These population sectors consume goods, and produce units of "labor," which may be


environmental facilities
fellowships and scholarships
environmental facilities
primary and secondary educaation
higher education
vocational education
environmental facilities
unskilled manpower
skilled manpower
"professional" manpower
faculty and staff
new students
Developed Manpower
other Employment
research and other services

→ vector flows of people and services with associated imputed values per unit

● interfaces with remaining socio-economic process (terminals)

◌ population groups and their imputed values (internal states)

Figure 1:5.2-I Basic Structure of the Manpower Sector of an Economy

represented by a vector $\underline{\ell}(t)$. They also produce new members of the population, who will return, in time, to the educational system.

Clearly, a unit "value of education," determined by the production costs of the education sector, may be attributed to each category $m_i(t)$ of $\underline{m}(t)$. This value of education, together with the cost of living, determines a vector $\underline{\ell}(t)$ of unit values of labor produced by each category.

Part of the labor produced by these categories combines with other inputs of the industrial sector of the economy to produce a gross national product $Y(t)$, part is channeled into government or other "maintenance" sectors, and part is returned as input to the educational system. Excesses or deficiencies of labor may be represented by a vector $\underline{\ell}(t)$ of positive or negative flows from each manpower category.

The values or *costs* $\underline{\ell}(t)$ of units of labor produced are negative numbers. If the positive unit values $\underline{\ell}'(t)$ represent the average *paid* for each category of manpower, then the vector

$$\underline{\omega}(t) = \underline{\ell}(t) + \underline{\ell}'(t)$$

represents the positive or negative difference between the cost or imputed value of labor produced and the price actually paid for that labor. The variables $\omega_i(t)$ are interpreted as representing the economic value which is added to manpower by the educational process. A negative value indicates that the cost of the education exceeds its value to the economy.

1:5.3 Mathematical Form of the Model of Education in the National Economy

The transitions and inputs of manpower, and the outputs of labor, of the population sector are established as

1:5.3a $$\underline{m}(t) = A\ \underline{m}(t-1) + \underline{d}(t)$$

and

$$\underline{\ell}(t) = B\ \underline{m}(t)\ .$$

The diagonal elements of the matrix A represent the "survival" rates of the respective groups. The other elements of A represent the rates at which educated personnel revert to lower capabilities, advance to higher capabilities, train themselves in new skills, or otherwise change status. The matrix B represents the utilization rates of the various categories.

If it is now assumed that both the number of units of trained manpower and the research and other services required by government and industry from the education sector are directly proportional to the gross national product Y(t), the result is

$$\begin{bmatrix} \underline{\ell}(t) \\ \\ \underline{o}(t) \end{bmatrix} = \begin{bmatrix} \underline{\theta}_{\ell} \\ \\ \underline{\theta}_{o} \end{bmatrix} \quad Y(t)$$

where the vector $\underline{\theta} = [\underline{\theta}_{\ell}, \underline{\theta}_{o}]^{\Gamma}$ represents coefficients of proportionality.

When the models characterizing the transitions and input-output flows of the educational system are combined with models of the manpower and industrial sectors, with appropriate constraints, a first approximation of the overall flows is established. An attempt to define the structure in detail will not be made. Now, however, an examination of the influence of a control variable of the education sector, such as $\underline{h}(t)$ (fellowships and scholarships), on the manpower categories of the population sector can be made. In the model of a single university, the parameter matrices K_1 and K_2 (proportions of enrollment attributed to financial aid) and K_{11} and K_{21} (proportion of enrolled students who remain in school because of financial aid) will be distinct, because part of the financially induced enrollment will be drawn from other schools. However, in a model of the aggregated educational system, it may be assumed that $K_{11} = K_1$ and $K_{21} = K_2$.

The education-manpower flows as developed from equations 1:3.1.2a, 1:3.1.3a and 1:5.3a can now be described. The vector $\underline{s}(t)$ represents categories of students in all levels of education.

$$\begin{bmatrix} \underline{s}(t) \\ \underline{m}(t) \end{bmatrix} = \left[\begin{array}{c|c} B^{-1}\,P(t) & A' \\ \hline D(t) & A \end{array}\right] \begin{bmatrix} \underline{s}(t-1) \\ \underline{m}(t-1) \end{bmatrix}$$

$$+ \begin{bmatrix} B^{-1}\,a(t) \\ O \end{bmatrix} n(t) + \begin{bmatrix} 0 \\ -B^{1} \end{bmatrix} s(t) + \begin{bmatrix} B^{-1}\,K_1V_2G_3 \\ -\,K_1V_2G_3 \end{bmatrix} \theta_o\, Y(t) + \begin{bmatrix} B^{-1}K_2 \\ -K_2 \end{bmatrix} h(t)$$

The matrix A' indicates transition from the labor force back into the educational sector.

The numerical value of the excess or deficiency of labor as a function of time may be represented as a function of the student and manpower populations, and the gross national product, by

$$\underline{\ell}(t) = M \begin{bmatrix} \underline{s}(t) \\ \\ \underline{m}(t) \end{bmatrix} - \underline{\Phi}\, Y(t)$$

The model of education in the national economy given here must be considered as being very preliminary in nature. No attempt has been made to establish valid parameters for the model or its structure. It is included here to point the way to further work.

Part 2

THE MODEL IN DECISION MAKING

2: THE MODEL IN DECISION MAKING

2:1 Application to Decision Making

2:1.1 Introduction

To the extent that the model developed in Part 1 characterizes the flows of resources and students in an institution of higher education, it serves as a basis for a vast number of studies ranging from cost allocation to long-range planning and management. A complete survey of all such applications embraces almost the entire field of modern system theory. Consequently, only the salient and more obvious applications are presented here.

The simplest application of the model is its use as a descriptive tool to identify the past and current operation of the university. Beyond this simple application lie the applications which are more difficult to achieve but which offer the administrator new tools for use in planning applications such as prediction, simulation, and development of management policies.

The theoretical basis of the model is presented in Part 1. (Sections 1:2.1, 1:2.2 and 1:2.3 provide a brief, non-mathematical description.) The remaining steps that must be taken to establish the model as a management and decision tool include identification of the specific components of the various flow vectors in the model and the units used to measure them, development of an adequate data base from which to construct parameters and against which to measure the results of simulation, and actual tests of the model against historical records.

Development of the data base and estimation of parameters are discussed in 2:1.2 and 2:1.3. However, not all parameters need be evaluated before subparts of the model become useful instruments of decision making. Indeed, a validated model of the student sector can be implemented to determine the academic demands that the incoming stream of students place on the production facilities quite independently of a validated model indicating how these demands can or will be met by the production and resource sectors. Likewise, models of the production sectors can be parameterized, validated and implemented as a limited tool of decision making quite independently of the demand sector.

The most efficient use of the model requires record files that are available for machine processing and an integrated set of computer programs which are readily accessible for direct use by administrative offices. Rather than be overwhelmed with a quantity of data processed in standard form, each person responsible for some phase of university operation should be able to acquire rapidly the precise data he needs in the form most useful to him. Considerations important to the development of programs of this type are described in Part 3 of the report along with a set of programs designed for a class of simulations shown in Part 4.

2:1.2 Development of a Coordinated Data Base

The theoretical framework of the model can accommodate essentially any classification of internal states and any number of production and resource sectors. The extent of the data base required to evaluate the parameters in the model depends, of course, on the number of components identified in each vector of resources, outputs, or other flows.

The parameter matrices in each sector model are determined from the actual operating data of the university. The coefficients in the system model are then computed from the parameter matrices of the sectors. Except in the case of highly aggregated variables, it is impractical to implement the model unless the parameter matrices can be evaluated from a data base addressable by a computer. Further, the model is an effective tool in decision making only if the parameters can be updated periodically -- perhaps annually.

Tremendous strides have actually been made by most universities in the use of computers in their operations, and these are important contributions toward making a simulated model of the type proposed here a workable tool. It is unfortunate, however, that the various administrative units have had no real reason to expend the additional effort necessary to coordinate their sources of data, coding systems, and processing routines. Generally speaking, viewing any given administrative unit as a separate entity, present processing procedures can be classified as accurate and efficient. The problem arises when one attempts to view the entire university as a single operating system rather than a series of autonomous units. It is usual to find that some of the data required are not available at all, some are of questionable accuracy, and some are stored in different locations using different coding systems. The existence of this data problem is not a reflection on the operation of the administrative units of the university but rather is a condition which prevails in general and in this sense reflects the "state of the art."

A technical description of data base development is presented in 3:1, based on existing and planned record files at Michigan State University. Two files are available at the present time for establishment of the parameters of the student sector a Student Master Record and a Class Card Record.

As part of the registration process a Student Master Record is compiled each term which contains the enrollment data on each student registered for that term. At the end of the term this file is stored and becomes a part of the university historical record. These records in their present machine addressable form are available for each term since Fall 1963.

The Class Card Record contains one record for each class taken by each student. It identifies the student as well as the course and the field-level category for both the student and the course. The records now available do not carry information on graduation status, and the process for resolving this deficiency has not yet been determined, although a request has been issued to incorporate this information in the basic student record. In the meantime the only way to determine how many students are still present as graduate students is to merge this record with the graduating list. Although there is a clear solution to this problem in the future, it points up the sort of difficulty that can arise until an adequate data base is established.

Unfortunately no files currently exist which contain sufficient information to determine the influence that fellowships, assistantships, etc., have on enrollments in the various fields and levels. There are also some difficulties encountered in establishing the coefficients that relate to teaching-research at the doctoral level, inasmuch as Michigan State does not require these students to register for each term of residence during which they are conducting research for their doctoral dissertations. They are only required to accumulate a fixed number of research credits by the time the thesis is completed. This requirement essentially assures payment of the required fee. Consequently, the model as it pertains to this level of education cannot be accurate unless there is an adjustment in the policy on graduate student enrollment.

The problem of determining the number of postdoctoral students enrolled at any given point in time also presents some difficulty inasmuch as no formal registration is required of them by this university. Further, it is not clear how they can be identified through present faculty records. Unless some formal procedure is established whereby records are kept on students at this level it will be very difficult, if not impossible, to fill this void in the model.

One important area where an adequate data base must be developed is faculty effort. The theoretical model clearly identifies the faculty information needed: cost of faculty (salaries, supporting staff, etc.), time allocations, rank, function (teaching, research, administration, etc.). In this particular area, the needs of the simulation effort have coincided with needs of the university administrative offices, and a data base has been designed (see 4:2). The development is complicated by a variety of problems. Standard coding procedures must be developed so data can be merged, data acquisitions must be synchronized in time, and provisions must be made to insure adequate protection against improper release and use of information, protection of individual rights and safeguards against unauthorized use.

Many areas remain in which an adequate data base is not currently available, and probably will not be for the next few years. In these cases it is necessary, at least for the present, to use subjective estimates or to omit them from the model. Efforts are being made to develop files of building space facilities such as classrooms, laboratories, auditoria, offices, etc. Once this is completed, it should be possible to develop a "Space Master Record", similar to the Student Master Record, to record the use to which each facility has been assigned during each term.

For other types of physical facilities, the problem of development of units of measurement must be solved. It may be appropriate to measure the use of classrooms in hours per week or per term, but if time is used to measure computer use, the data will not be comparable for different machines. The same problem arises with other types of technological equipment.

Measurement of many types of supplies is most easily recorded in terms of dollar value. However, the cost data for each record must be adjusted according to some arbitrarily selected base year, so that increased use can be distinguished from monetary inflation.

Because of the need for periodic updating, it is essential that the data identified by the flow vectors of the system model be easily and objectively obtained. Such things as physical resources used, costs, personnel, or student enrollments are routinely a part of university records. The more difficult data problems lie in identifying the resource use in various phases of production. The problem of allocating personnel effort is discussed in 1:3.3.1. The reliability of self-evaluation questionnaires is questionable. In addition, over a period of time, such evaluations are likely to reflect the emerging awareness on the part of faculty and staff of the way in which the administration is using these data. The problem of evaluating the influence of controls is also discussed in 2:1.3, 2:4. Data obtainable only by extended surveys, in general, do not promote efficient use of the model. In fact, it may frequently be more desirable to use the expert judgment of experienced university administrators about parameter values than to rely on inadequate or questionable sample surveys.

2:1.3 Parameter Estimation

When an integrated data base has been developed, as described in 2:1.2, the parameters of the sector models can be machine evaluated for any given time period.

The parameter matrices in the student sector (see 1:3.1.1) of the model can be divided into two classes: those related to population movement through the university and those related to the demands the population places on the university resources. The transition of the state vector, representing student population distribution, from one time period to another is governed by the transition matrix P(t) and the new-arrival distribution vector $\underline{a}(t)$. Estimates of the entries $p_{ij}(t)$ and $a_i(t)$ can be made from student record files such as those described in 2:1.2.

The matrix P(t) of student transitions is most easily obtained if permanent student files contain the explicit term-by-term history of each student's status with respect to field and level. Otherwise, the transition matrix must be obtained from the files of the terms for which the transition matrix is desired. In the latter procedure a means of easily comparing files is necessary. At Michigan State University the sequential assignment of student numbers has facilitated this comparison. (See 3:1).

In either case, the number N_{ij} of students who have transferred from category j to category i, from time period t-1 to time period t, is obtained first. The initial estimate of the transition matrix P(t) has entries

$$p_{ij}(t) = \frac{N_{ij}}{N_{1j} + N_{2j} + \ldots + N_{nj}}$$

which is simply the proportion of students from category j who have transferred to category i.

The initial estimate of the vector $\underline{a}(t)$ describing the distribution of new students is similarly obtained by first counting the number N_{io} of new students who enter each category. Then

$$a_i(t) = \frac{N_{io}}{n(t)}$$

where n(t) is the total number of new students.

The entries $\delta_j(t)$ of the diagonal departure matrix D(t) are obtained from the number d_{oj} of students from category j who do not return for time period t. The ratio

$$\delta_j(t) = \frac{d_{oj}}{s_j(t-1)}$$

is the proportion of students in category j who do not return. Theoretically, the entries in D(t) can be computed as

$$\delta_j(t) = 1 - \sum_{i=1}^{N} p_{ij}(t).$$

However, round-off errors in the estimates of the $p_{ij}(t)$ can cause considerable discrepancies, and direct computation is preferable.

If student transition information is to be obtained in form

1:3. 1. 2a, where part of the enrollment is attributed to the influence of financial aids, P(t) and $\underline{a}(t)$ must be modified as described in 1:4. 6. For these computations it is necessary to first estimate the proportion of new and returning students in each category whose presence may be attributed to the influence of financial aid. If these estimates are taken as the proportions of students actually receiving aid, the influence of the controls may be exaggerated, since many students who are receiving aid would be enrolled even if the aid had not been available. Therefore, it is suggested that the influence of financial aid be established by determining the probability that a student would not be enrolled without the aid. If a student is not receiving aid, this probability is considered to be zero. The proportion of enrollment attributed to financial aid may then be established as the average of these probabilities for students in each category.

Details of a survey to determine the parameters on the influence of financial aids are presented in 2:4. If the control variables are to be included as a permanent part of the model, some means must be devised of updating these parameters from information that can be made part of the student master record.

The entries in matrices C and R describing average credit distribution are computed from records of course enrollment. An entry c_{ij} or r_{ij} is obtained by first counting the total number of student credits in classification i being carried by students in category j, and dividing by the total number of students in category j.

The entries in the parameter matrices of the production and resource sectors are input-output ratios and are computed directly from data files. In each case the ratio is:

$$\frac{\text{No. of units of resource}}{\text{No. of units of production}}$$

Many of these parameters coincide with factors used in various resource-planning schemes. For example, the "Space Use Factor" defined by Middlebrook [82] is the ratio of assignable space being used to the measure of usage. Implementation of computer programs for parameter estimation can be coordinated with all ongoing campus planning activity.

Figure 2:1.3.I provides a schematic representation of the parameter estimation process.

2:1.4 The Model as a Descriptive Tool for Operations Analysis

Among the major objectives which motivate the construction of a dynamic mathematical model of the university is the analysis of the existing structure and procedures. Within the framework of the model, the relationships of the various components of the institution are clarified, and the patterns by which university administrators currently allocate scarce resources to meet constantly changing demands are described quantitatively.

When the data files for a given time period are used to compute numerical values for the parameters and variables of the model, the resulting statistics may be used to analyze current operations. More important is the fact that these statistics, re-calculated for several successive time periods, provide a dynamic description, revealing trends or changes in demand, output, and operating policy

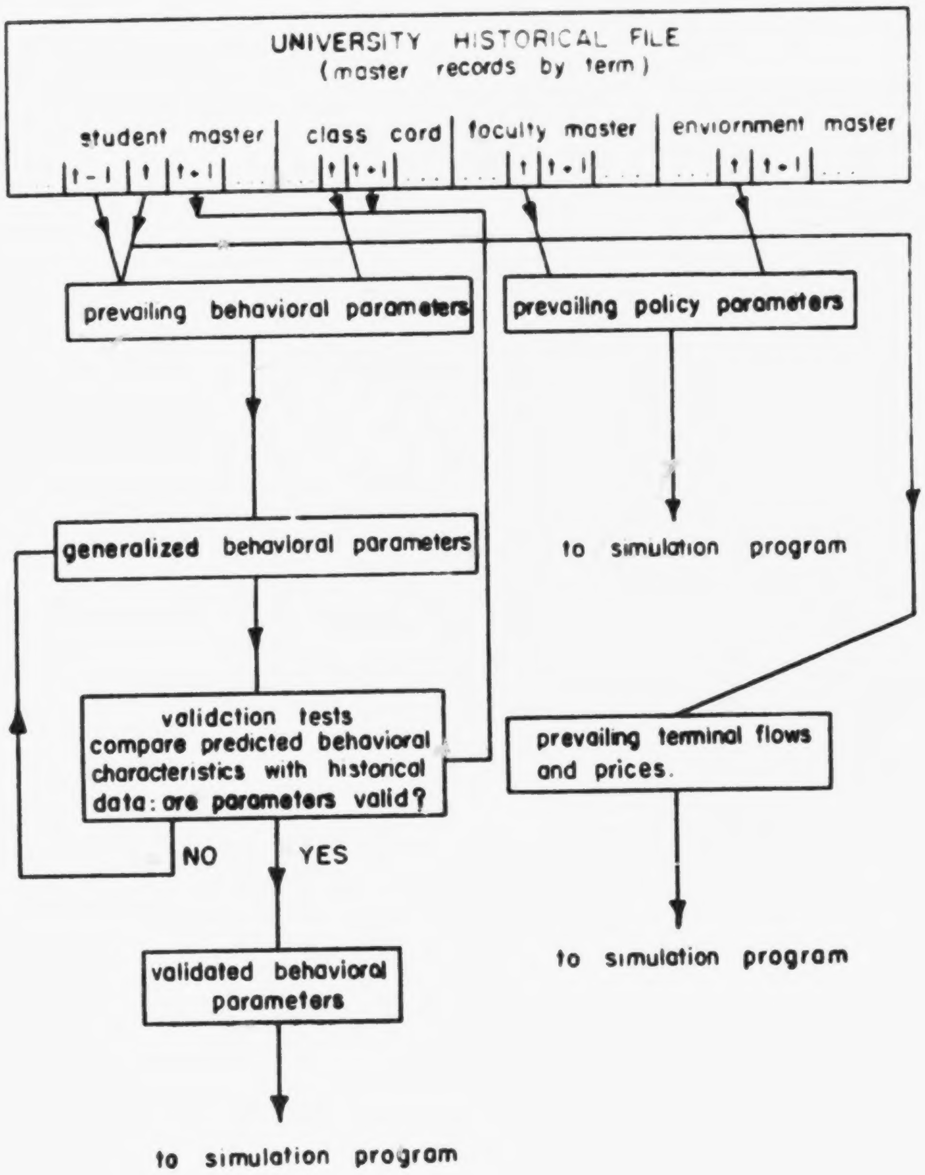

UNIVERSITY HISTORICAL FILE
(master records by term)
student master
t-1
t
t+1
class card
t
t+1
faculty master
t
t+1
enviornment master
t
t+1
prevailing behavioral parameters
prevailing policy parameters
to simulation program
generalized behavioral parameters
validation tests
compare predicted behavioral characteristics with historical data: are parameters valid?
NO
YES
prevailing terminal flows and prices.
to simulation program
validated behavioral parameters
to simulation program

Figure 2:1. 3-I Logical Flow Diagram of Data Processing Program for Evaluating and Updating Parameters in Simulation Model

which have been or are occurring. It is likely that many of the policies by which a university is governed have never been explicitly stated and perhaps are not even recognized as policies. Thus by defining the existing behavior of the system, the model can present a picture of how resources are being utilized in production in the university.

It is true, of course, that most universities have data-processing offices which provide administrators with statistical descriptions of all phases of university operation. However, these data are frequently presented and analyzed separately for each phase of university operation, so that important relationships remain obscure. Data-processing within the framework of the system model offers several advantages. The model presents an explicit relationship among all the variables in the system. Faculty requirements, for example, can be related not only to student credits but directly to enrollments; and not only to enrollments in one department but to all fields and levels of the university. If data are available, these requirements are simultaneously related to the output of research and other services, and these functions of the university may be compared directly to the teaching function in terms of resource demands.

Because the model establishes unit costs associated with all resource flows, it can be used to determine total budgets for special programs or to determine auxiliary costs to the university of projects done under grants to particular departments.

The following examples illustrate the use of parameters and variables of the model as descriptive statistics. These examples are based on Michigan State University operating data and are necessarily limited in scope because of limitations on the data available.

Student Transition Tables

Tables 2:1.4 I, II, III, IV present the student transition matrices (denoted by P(t) in the mathematical model) for four successive years. In this example, the field designations for students represent the Colleges of Engineering, Natural Science, and Business as separate fields, aggregating all departments within those colleges. A fourth field, designated as "other," includes the remaining colleges of the university*, and aggregates approximately 70% of the total student body. The number of fields has been limited to four purely for illustrative purposes, although the choice of categories is useful in examining the operation of individual colleges. The six levels in the example are the freshman, sophomore, junior, senior, masters and doctoral levels. The undergraduate levels are defined by the university administration in terms of number of credits earned. Graduate levels are somewhat arbitrary, since the masters or doctoral level status may be based on a student's intentions rather than credits earned.

The four tables represent transition proportions from Fall term of one year to Fall term of the next year, for the years 1963-64,

---

*Colleges of Agriculture, Arts and Letters, Communication Arts, Education, Home Economics, Human Medicine, Social Science and Veterinary Medicine; University College; and three Residential Colleges: Justin Morrill, James Madison and Lyman Briggs.

1964-65, 1965-66 and 1966-67. In practice, tables may be computed for any pair of terms for which records are available.

As descriptive statistics, these matrices, or tables, depict the pattern of student movements, and in particular, the behavioral pattern of students who transfer from one college to another. For example, the first column of table 2:1.4.I shows how students who were registered as freshmen in Engineering Fall term of 1963 were distributed the following year. The row designations show the Fall 1964 status. It indicates that 2% returned as freshmen and 55% as sophomores in Engineering. It shows also that 16% of the Engineering freshmen returned as sophomores in one of the "other" colleges. In fact, the row designated as "Other : Soph" shows that 16% of the freshmen in Engineering, 18% of the freshmen in Natural Science, and 10% of the freshmen in Business had transferred to some "other" college for the sophomore year.

The four transition tables computed so far are remarkably stable, considering the many administrative policy changes in admissions, curriculum, and organization which occurred from 1963 to 1967. In addition, the university absorbed its share of the post-World War II "baby boom," growing from approximately 25,500 to more than 38,800 students, and felt the effects of changing government policies on the military draft.

It is probable that a detailed study of student transition parameters would establish the causal factors for some of the variability in the entries from year to year. One illustration is the variability in the number of freshmen Engineers returning as sophomores in the same college. The figures are 55%, 48%, 55% and 47% for four successive transitions. This fluctuation seems related to the proportion who transfer to "other" colleges (16%, 21%, 16%, 21%). The same transitions, for the College of Natural Science, show a sharp drop in the proportion of freshmen who remain in the college for the 1966-67 transition. This variability has been tentatively related to certain changes in admission policies and the resulting changes in student quality.

One other apparent change in transition patterns deserves mention. In three of the four fields, including "other", the proportion of masters candidates who return at that level drops noticeably for the 1966-67 transition, while the proportion who have advanced to doctoral status is greatly increased. This pattern is not true for the College of Business. This can be explained by the fact that graduate student draft deferments were abolished early in 1967. Current masters candidates were granted one year to obtain their degrees, and doctoral candidates were granted five years. Thereupon, many departments immediately listed all graduate students as "doctoral," and of course, many of the students themselves decided upon a change of status. However, this was not possible in the College of Business, where the masters and doctoral programs are quite different, even at the first-year graduate level.

It is anticipated that a similar transition table, computed for the Fall 1967-Fall 1968 transition, will provide important information on the effects of the draft on college enrollments.

Further discussion of the transition tables is presented in 2:3.

Course Credit Distributions

Tables 2:1.4.V, VI, VII, VIII and IX present credit distribution tables (denoted by the matrix C in the mathematical model) for the Fall terms of 1963 through 1967. The column headings are field-level categories of student enrollment, corresponding to the four fields and six levels of the transition tables. The row headings designate field-level classifications of courses, including independent research done for credits. In this example, the courses are classified in the same four fields as the student enrollment: College of Engineering, College of Natural Science, College of Business, and "other." Courses are separated into three levels: Freshman-Sophomore, Junior-Senior, and Graduate.

A single column of a credit distribution table describes the average distribution of credits for students in the category corresponding to that column. Thus, the third column of Table 2:1.4.V indicates that during Fall term of 1963, a junior in Engineering took, on the average, 2.25 credits in freshman or sophomore engineering courses, 6.73 credits in junior-senior level engineering, a total of 4.01 credits in the College of Natural Science, 3.12 credits in "other" colleges, and a fraction of a credit in the Business College.

A single row of the table describes the source of the credit load for a particular field-level classification. Since the University College, which administers several required undergraduate courses, is grouped with the "other" colleges, the row corresponding to "Other : Freshman - Sophomore" courses indicates a heavy demand from students in all fields.

Variations in credit distribution from year to year reflect changing behavior patterns in choice of electives, changing degree requirements, and the adding or discontinuing of courses.

Useful analysis of trends in credit demands probably requires less aggregation of departments in the choice of field designations. The tables shown here are used for illustration only. Nevertheless, several interesting patterns are discernable. The average number of credits in undergraduate engineering courses, taken by students in Natural Science and Business, shows a steady increase. This can tentatively be explained by the growing popularity of courses in Computer Science given by the College of Engineering. A second noticeable trend is the increasing demand for credits in the College of Natural Science. Much of this increase is due to the growing need for mathematics.

Distribution of New Students

Table 2:1.4.X describes the percentage distribution of new students into 24 field-level enrollment categories for four successive years. The data describe Fall term admissions and include transfer students and students who are re-enrolling after being absent the previous year. Since undergraduates are not required to state a major preference until the junior year, these statistics contain only limited information on degree plans of new students.

The columns of this table correspond to the vector $\underline{a}(t)$ in the mathematical model.

Departures

Entries in Table 2:1.4.XI describe the percentage of students in each category who left the university, for four successive school years. Unfortunately, the data files in their present form do not provide a means for determining which of the departing students received degrees. It should also be noted that the proportion of "departing" seniors does not include students who receive the bachelor's degree and continue with graduate work. These students are counted as part of the transition from senior to graduate levels in the transition tables.

The columns of data in the departure table correspond to the diagonal entries of the matrix D(t) in the mathematical model.

Faculty Effort Used in Teaching

Table 2:1.4.XII illustrates the time variation in parameters describing the utilization of faculty effort in teaching. The parameter represents the number of full-time equivalent faculty required per single student credit produced. In this table, all full-time faculty have been aggregated for each of eleven colleges of the university. Faculty percentages of effort devoted to teaching, research, professional service, and administrative committee work were evaluated separately for each department by the department chairmen. The data pertain to Fall term of the year indicated.

The data indicate the variation among colleges in utilization of faculty effort in teaching. Much of this variation is accounted for by the organization of this university. Most students are considered to be enrolled in the two-year University College during the freshmen and sophomore years, and several required introductory courses are in the University College classification. Some colleges, therefore, teach few or no large lower undergraduate classes.

If machine addressable data files were available, as described in 2:1.2, the parameters could be computed separately for graduate and undergraduate credits, for faculty separated by rank, or for graduate assistant effort. In addition, similar data on use of technological equipment would reveal to what extent the use of faculty has been replaced by the use of closed-circuit TV and other devices.

In all the examples presented here, no systematic attempt has been made to determine the causes or interpretation of variations in the data over periods of time. The tables are exhibited as examples of descriptive use of the model. It is clear, however, that many of the changes can be associated with specific policies or procedures of administration of the university. Therefore, they provide a means for objective analysis of university operation. In addition, they reveal behavioral trends of students in relation to the academic programs.

TABLE 2:1.4 I STUDENT TRANSITION TABLE - FALL 1963--FALL 1964

```
    STUDENT TRANSITION TABLE=PERCENTAGE DATA
                ENGINEER                         NAT.SCI.                         BUSINESS                          OTHER
ENGIN   FRSH SOPH JUN  SEN  MSTR DCTR    FRSH SOPH JUN  SEN  MSTR DCTR    FRSH SOPH JUN  SEN  MSTR DCTR    FRSH SOPH JUN  SEN  MSTR DCTR

FRSH    0.02

SOPH    0.55 0.03                        0.00

JUN     0.01 0.46 0.00                        0.01

SEN          0.03 0.70 0.31                             0.00

MSTR                   0.07 0.39 0.01

DCTR                        0.06 0.61
N. S.   FRSH SOPH JUN  SEN  MSTR DCTR    FRSH SOPH JUN  SEN  MSTR DCTR    FRSH SOPH JUN  SEN  MSTR DCTR    FRSH SOPH JUN  SEN  MSTR DCTR

FRSH                                     0.02 0.00

SOPH                                     0.57 0.05                                                         0.00

JUN          0.02 0.01                   0.02 0.55 0.07                        0.00                             0.03

SEN               0.02 0.01                   0.03 0.68 0.24                                                         0.00

MSTR                   0.00                             0.06 0.46 0.00

DCTR                                                         0.07 0.64
BUS.    FRSH SOPH JUN  SEN  MSTR DCTR    FRSH SOPH JUN  SEN  MSTR DCTR    FRSH SOPH JUN  SEN  MSTR DCTR    FRSH SOPH JUN  SEN  MSTR DCTR

FRSH    0.00                                                              0.01

SOPH    0.05 0.01                        0.02                             0.58 0.09                        0.01

JUN          0.05                             0.03                        0.00 0.53 0.06                        0.04 0.00

SEN               0.02 0.01                        0.01 0.00                   0.04 0.68 0.20                        0.01

MSTR                   0.04                                                              0.04 0.18                        0.00 0.00

DCTR                                                                                          0.02 0.75                             0.01
OTHER   FRSH SOPH JUN  SEN  MSTR DCTR    FRSH SOPH JUN  SEN  MSTR DCTR    FRSH SOPH JUN  SEN  MSTR DCTR    FRSH SOPH JUN  SEN  MSTR DCTR

FRSH    0.01                                                              0.01                             0.03

SOPH    0.16 0.01                        0.18 0.02                        0.10 0.01                        0.66 0.07

JUN          0.13 0.01                   0.00 0.12 0.01                        0.08 0.00                   0.01 0.54 0.06

SEN               0.08 0.02                   0.01 0.08 0.03                        0.05 0.00                   0.04 0.71 0.19

MSTR                   0.01                             0.03 0.00                        0.00 0.02              0.00      0.05 0.36 0.00

DCTR                                                         0.00 0.00                             0.00                        0.06 0.54


COL TOT 556  417  252  298  107   88     533  352  466  594  396  331     509  537  842  930  233  104     4653 4000 3080 4065 2230 1340
```

TABLE 2:1.4 II STUDENT TRANSITION TABLE - FALL 1964--FALL 1965

```
        STUDENT TRANSITION TABLE=PERCENTAGE DATA
                  ENGINEER                          NAT.SCI.                         BUSINESS                          OTHER
ENGIN   FRSH SOPH JUN  SEN  MSTR DCTR    FRSH SOPH JUN  SEN  MSTR DCTR    FRSH SOPH JUN  SEN  MSTR DCTR    FRSH SOPH JUN  SEN  MSTR DCTR

FRSH    0.03

SOPH    0.48 0.04 0.00                   0.01

JUN     0.00 0.47 0.03                        0.01

SEN          0.01 0.73 0.37                        0.00 0.00

MSTR                   0.08 0.30

DCTR                        0.16 0.68
N. S.   FRSH SOPH JUN  SEN  MSTR DCTR    FRSH SOPH JUN  SEN  MSTR DCTR    FRSH SOPH JUN  SEN  MSTR DCTR    FRSH SOPH JUN  SEN  MSTR DCTR

FRSH                                     0.02

SOPH    0.02                             0.53 0.04                        0.00                             0.00

JUN          0.09 0.30                   0.02 0.52 0.05                                                         0.03

SEN               0.02      0.00         0.00 0.03 0.68 0.25                                                         0.00

MSTR                                                    0.08 0.46 0.00

DCTR                                                         0.13 0.54
BUS.    FRSH SOPH JUN  SEN  MSTR DCTR    FRSH SOPH JUN  SEN  MSTR DCTR    FRSH SOPH JUN  SEN  MSTR DCTR    FRSH SOPH JUN  SEN  MSTR DCTR

FRSH                                                                      0.03

SOPH    0.05 0.01                        0.02                             0.56 0.07                        0.01

JUN          0.00 0.00                        0.02                        0.01 0.54 0.06                        0.03

SEN               0.01                             0.01                   0.00 0.02 0.68 0.24

MSTR                   0.05 0.01                                                         0.06 0.34 0.01

DCTR                                                                                          0.03 0.64
OTHER   FRSH SOPH JUN  SEN  MSTR DCTR    FRSH SOPH JUN  SEN  MSTR DCTR    FRSH SOPH JUN  SEN  MSTR DCTR    FRSH SOPH JUN  SEN  MSTR DCTR

FRSH    0.03                             0.00                             0.01                             0.04

SOPH    0.21 0.07                        0.18 0.03                        0.12 0.03                        0.69 0.07

JUN          0.10 0.01                        0.17 0.01                        0.09 0.00                   0.01 0.58 0.07

SEN               0.07 0.03                   0.01 0.05 0.01                        0.02 0.01                   0.03 0.72 0.22

MSTR                                                    0.02 0.03 0.00                   0.01                   0.00      0.06 0.38 0.00

DCTR                                                         0.03 0.00                                                         0.08 0.55


COL TOT 732  410  291  314  121  83      642  452  556  625  504  353      525  527  904 1057  457  160     5752 4420 3696 4499 2558 1444
```

TABLE 2:1.4 III STUDENT TRANSITION TABLE - FALL 1965--FALL 1966

```
    STUDENT TRANSITION TABLE-PERCENTAGE DATA
                  ENGINEER                         NAT.SCI.                         BUSINESS                         OTHER
ENGIN   FRSH SOPH JUN  SEN  MSTR DCTR    FRSH SOPH JUN  SEN  MSTR DCTR    FRSH SOPH JUN  SEN  MSTR DCTR    FRSH SOPH JUN  SEN  MSTR DCTR

FRSH    0,03           0,01

SOPH    0,25 0,02                        0,01

JUN          0,49 0,04                        0,01

SEN          0,01 0,76 0,31 0,00

MSTR                   0,07 0,31

DCTR                        0,07 0,71
N. S.   FRSH SOPH JUN  SEN  MSTR DCTR    FRSH SOPH JUN  SEN  MSTR DCTR    FRSH SOPH JUN  SEN  MSTR DCTR    FRSH SOPH JUN  SEN  MSTR DCTR

FRSH                                     0,01           0,00

SOPH    0,00                             0,56 0,03                        0,00

JUN          0,03 0,00                   0,01 0,59 0,04                        0,00                             0,02

SEN               0,02 0,00              0,00 0,05 0,71 0,23                                                         0,00

MSTR                   0,00                             0,07 0,44 0,00

DCTR                                                         0,09 0,73
BUS.    FRSH SOPH JUN  SEN  MSTR DCTR    FRSH SOPH JUN  SEN  MSTR DCTR    FRSH SOPH JUN  SEN  MSTR DCTR    FRSH SOPH JUN  SEN  MSTR DCTR

FRSH                                                                      0,03

SOPH    0,03                             0,01                             0,29 0,05                        0,00

JUN          0,04                             0,02                        0,00 0,63 0,05                        0,03

SEN               0,01                             0,01 0,00              0,01 0,03 0,72 0,25                        0,00

MSTR                   0,05 0,00                        0,00 0,01                        0,07 0,31 0,02

DCTR                        0,00                                                              0,04 0,62
OTHER   FRSH SOPH JUN  SEN  MSTR DCTR    FRSH SOPH JUN  SEN  MSTR DCTR    FRSH SOPH JUN  SEN  MSTR DCTR    FRSH SOPH JUN  SEN  MSTR DCTR

FRSH    0,01                             0,01                             0,00                             0,04

SOPH    0,16 0,04                        0,16                             0,10 0,00                        0,68 0,06

JUN          0,19 0,01                        0,12 0,01                        0,05                        0,01 0,29 0,06

SEN               0,07 0,01                   0,00 0,04 0,01                        0,03 0,00              0,00 0,03 0,73 0,20

MSTR                   0,00                             0,03 0,01                        0,01 0,00 0,00                   0,06 0,42 0,00

DCTR                                                         0.01                                                              0,04 0,57


COL TOT 793  442  284  385  119  103     774  504  590  701  563  420     673  726  905  1057 575  178     6800 5497 4190 4703 2947 1548
```

TABLE 2:1.4 IV STUDENT TRANSITION TABLE - FALL 1966--FALL 1967

```
   STUDENT TRANSITION TABLE=PERCENTAGE DATA
               ENGINEER                    NAT.SCI.                         BUSINESS                        OTHER
ENGIN   FRSH SOPH JUN  SEN  MSTR DCTR   FRSH SOPH JUN  SEN  MSTR DCTR   FRSH SOPH JUN  SEN  MSTR DCTR   FRSH SOPH JUN  SEN  MSTR DCTR

FRSH    0,02

SOPH    0,47 0,01                       0,02

JUN     0,00 0,42 0,03 0,00                  0,01

SEN          0,01 0,68 0,21                       0,01

MSTR                   0,03 0.18

DCTR                   0,03 0,19 0,69
V. S.   FRSH SOPH JUN  SEN  MSTR DCTR   FRSH SOPH JUN  SEN  MSTR DCTR   FRSH SOPH JUN  SEN  MSTR DCTR   FRSH SOPH JUN  SEN  MSTR DCTR

FRSH                                    0,01

SOPH    0,00                            0,49 0,03                                                       0,00

JUN          0,06 0,00                  0,01 0,50 0,04                                                       0,02

SEN               0,03 0.00 0.00             0,03 0,65 0.21                                                       0,01

MSTR                   0.00                            0.03 0.24 0,00

DCTR                                                   0,01 0,28 0,69
BUS.    FRSH SOPH JUN  SEN  MSTR DCTR   FRSH SOPH JUN  SEN  MSTR DCTR   FRSH SOPH JUN  SEN  MSTR DCTR   FRSH SOPH JUN  SEN  MSTR DCTR

FRSH                                                                    0,02

SOPH    0,05 0,01                       0,02                            0,59 0,06                       0,01

JUN          0,08                            0,05                       0,00 0,55 0,04                       0,04

SEN               0,02 0,00                       0,02 0,00             0,01 0,01 0,65 0,20                       0,01

MSTR                   0,03      0,00                       0,00 0,00                  0,05 0,33

DCTR                                                                                        0,05 0,65
OTHER   FRSH SOPH JUN  SEN  MSTR DCTR   FRSH SOPH JUN  SEN  MSTR DCTR   FRSH SOPH JUN  SEN  MSTR DCTR   FRSH SOPH JUN  SEN  MSTR DCTR

FRSH    0,02                            0,01                            0,00                            0,02

SOPH    0,21 0,04                       0,21 0.02                       0,12 0.01                       0,67 0,06

JUN          0,16 0,01                       0,16 0,01                  0,00 0.11 0,02                  0,01 0,58 0,06

SEN               0,08 0,01                  0,00 0,08 0.01                  0,01 0,08 0,02             0,00 0,03 0,72 0,19

MSTR                   0,01                       0,01 0,03 0,01 0,00                  0,01 0,00                 0,00 0.00 0,05 0,30 0,00

DCTR                                                        0.00                                                       0.00 0.15 0.56


COL TOT 808  540  326  377  138  105    793  572  643  735  600  551    549  573  1015 1145 762  217    6444 6151 4064 5111 3446 1621
```

3

TABLE 2:1.4.V CREDIT DISTRIBUTION TABLE - FALL 1963

Average Credits Per Student [Rows Correspond to Course Classifications; Columns Correspond to Student Categories]

		ENGINEERING						NATURAL SCIENCE					
		Frsh.	Soph.	Jun.	Sen.	Mstr.	Dctr.	Frsh.	Soph.	Jun.	Sen.	Mstr.	Dctr.
EGR.	Fr.-Soph.	2.49	2.19	2.25	.27	--	--	.03	.02	--	.04	.01	--
	Jun.-Sen.	.04	.24	6.73	10.82	.69	.10	--	--	.01	.04	.02	.01
	Grad.	--	--	--	.27	6.44	5.50	--	--	--	--	.01	.01
NAT. SCI.	Fr.-Soph.	6.20	6.18	.64	.11	.12	--	6.77	5.93	3.63	1.97	.66	.18
	Jun.-Sen.	.06	.85	3.37	1.66	1.57	1.00	.15	1.78	5.37	6.40	4.42	.95
	Grad.	--	--	--	.03	.53	.97	--	.02	.15	.42	3.26	5.15
BUS.	Fr.-Soph.	.02	.11	.02	.01	--	--	.02	.06	.04	.07	--	--
	Jun.-Sen.	.02	.14	.12	.33	--	--	--	.04	.09	.22	--	--
	Grad.	--	--	--	--	--	--	--	--	--	.01	.01	.01
OTHER	Fr.-Soph.	7.22	6.47	2.62	1.83	.03	.01	8.09	6.82	3.97	1.86	.21	.10
	Jun.-Sen.	--	.11	.50	.66	--	.10	.15	1.05	1.43	2.49	.50	.07
	Grad.	--	--	--	.01	--	--	--	--	--	.04	.19	.10

		BUSINESS						OTHER					
		Frsh.	Soph.	Jun.	Sen.	Mstr.	Dctr.	Frsh.	Soph.	Jun.	Sen.	Mstr.	Dctr.
EGR.	Fr.-Soph.	--	.02	--	.04	.01	--	.03	.06	.06	.05	.01	--
	Jun.-Sen.	--	--	--	.01	.02	--	--	.01	.05	.04	.03	.02
	Grad.	--	--	--	--	--	--	--	--	--	--	--	.03
NAT. SCI.	Fr.-Soph.	1.85	.82	.48	.25	.01	.54	1.64	1.30	.95	.44	.25	.06
	Jun.-Sen.	--	.04	.28	.26	.16	.04	.01	.16	.29	.43	.55	.38
	Grad.	--	--	--	.01	.01	--	--	--	--	.01	.38	.34
BUS.	Fr.-Soph.	1.98	2.26	1.01	.21	.08	--	.13	.21	.09	.05	.02	--
	Jun.-Sen.	.28	1.69	7.14	9.24	1.79	.05	.02	.15	.49	.56	.08	.01
	Grad.	--	--	--	.06	6.93	3.94	--	--	--	.01	.05	.08
OTHER	Fr.-Soph.	9.70	9.21	3.83	2.02	.53	.08	12.14	11.45	5.96	2.44	.66	.09
	Jun.-Sen.	.13	.78	1.89	2.21	.36	.45	.33	1.90	6.91	9.28	2.37	.97
	Grad.	--	--	--	.04	1.34	1.58	--	--	--	.15	4.23	5.49

TABLE 2:1.4. VI CREDIT DISTRIBUTION TABLE - FALL 1964

Average Credits Per Student [Rows Correspond to Course Classifications; Columns Correspond to Student Categories]

		ENGINEERING						NATURAL SCIENCE					
		Frsh.	Soph.	Jun.	Sen.	Mstr.	Dctr.	Frsh.	Soph.	Jun.	Sen.	Mstr.	Dctr.
EGR.	Fr. -Soph.	1.45	1.43	2.36	.41	.06	.04	.04	.05	.05	.06	.02	.02
	Jun. -Sen.	--	.25	6.52	10.84	.41	.22	.01	.04	.08	.11	.08	.09
	Grad.	--	--	--	.16	6.43	4.38	--	--	.01	.01	.03	.01
NAT. SCI.	Fr. -Soph.	6.70	7.85	1.34	.38	.03	--	6.63	5.75	3.79	1.91	.61	.20
	Jun. -Sen.	.03	.59	2.83	1.61	2.21	.76	.10	1.70	4.80	6.28	4.11	1.19
	Grad.	--	--	.01	.05	.90	1.55	--	.04	.11	.34	3.73	5.18
BUS.	Fr. -Soph.	--	.01	--	.01	--	--	.02	.05	.06	.05	.01	--
	Jun. -Sen.	--	.04	.09	.47	--	--	--	.03	--	.01	--	--
	Grad.	--	--	--	--	.02	--	--	--	--	--	.01	--
OTHER	Fr. -Soph.	5.77	5.54	2.37	1.66	.02	.05	7.73	6.42	3.84	2.29	.14	.11
	Jun. -Sen.	.02	.19	.50	.40	--	--	.11	1.13	1.37	2.30	.45	.08
	Grad.	--	--	--	--	.03	.05	--	--	.02	.03	.17	.05

		BUSINESS						OTHER					
		Frsh.	Soph.	Jun.	Sen.	Mstr.	Dctr.	Frsh.	Soph.	Jun.	Sen.	Mstr.	Dctr.
EGR.	Fr. -Soph.	--	.02	.02	.06	.01	.02	.02	.07	.05	.04	.01	.01
	Jun. -Sen.	--	--	--	.02	.02	.02	--	.01	.05	.07	.04	.02
	Grad.	--	--	--	--	.01	.05	--	--	--	--	.02	.05
NAT. SCI.	Fr. -Soph.	1.72	1.19	1.14	.77	.20	.41	1.49	1.22	.94	.42	.17	.06
	Jun. -Sen.	--	.01	.01	.02	.18	.28	.01	.14	.23	.49	.65	.36
	Grad.	--	--	--	--	.02	.02	--	--	--	--	.17	.37
BUS.	Fr. -Soph.	1.63	2.60	1.81	.45	.07	--	.11	.27	.06	.03	.01	--
	Jun. -Sen.	.15	.92	5.84	9.59	1.09	.03	--	.13	.46	.58	.06	--
	Grad.	--	--	--	.08	7.27	3.54	--	--	--	.01	.05	.05
OTHER	Fr. -Soph.	9.36	9.39	3.83	1.13	.22	.07	11.87	11.35	6.33	2.31	.70	.08
	Jun. -Sen.	.08	.50	1.87	2.32	.29	.33	.24	1.45	6.13	9.27	2.32	.95
	Grad.	--	--	.01	.02	.01	2.71	--	--	.01	.09	4.24	6.19

TABLE 2:1.4. VII CREDIT DISTRIBUTION TABLE - FALL 1965

Average Credits Per Student [Rows Correspond to Course Classifications; Columns Correspond to Student Categories]

		ENGINEERING						NATURAL SCIENCE					
		Frsh.	Soph.	Jun.	Sen.	Mstr.	Dctr.	Frsh.	Soph.	Jun.	Sen.	Mstr.	Dctr.
EGR.	Fr. -Soph.	.85	1.58	2.22	.56	--	--	.09	.04	.16	.17	.01	.02
	Jun. -Sen.	.03	.34	5.91	9.78	.50	.17	--	.09	.11	.13	.06	.04
	Grad.	.01	--	--	.01	5.90	5.27	--	--	--	--	--	.01
NAT. SCI.	Fr. -Soph.	7.60	7.53	1.43	.36	.04	--	6.38	6.42	3.81	1.79	.68	.15
	Jun. -Sen.	.06	.90	3.66	1.72	1.94	.67	.13	1.68	5.09	6.42	3.80	1.23
	Grad.	--	--	--	.04	.87	1.46	--	.04	.10	.33	3.72	5.72
BUS.	Fr. -Soph.	.02	.05	.02	.06	--	--	.03	.07	.03	.02	.01	--
	Jun. -Sen.	--	.04	.04	.49	--	--	--	.01	.04	.17	.01	--
	Grad.	--	--	--	.01	.07	--	--	--	--	--	--	--
OTHER	Fr. -Soph.	4.85	5.07	1.61	1.78	.03	--	7.28	6.33	3.83	2.03	.17	.03
	Jun. -Sen.	.01	.09	.37	.55	--	.03	.12	.97	1.24	2.46	.52	.03
	Grad.	.01	--	--	.04	--	--	--	--	--	.05	.16	.06

		BUSINESS						OTHER					
		Frsh.	Soph.	Jun.	Sen.	Mstr.	Dctr.	Frsh.	Soph.	Jun.	Sen.	Mstr.	Dctr.
EGR.	Fr. -Soph.	.01	.04	.05	.04	.02	.03	.02	.06	.05	.04	.01	.01
	Jun. -Sen.	--	.02	.02	.02	.02	.02	--	.02	.02	.03	.02	.01
	Grad.	--	--	--	--	.02	.05	--	--	--	--	.02	.05
NAT. SCI.	Fr. -Soph.	1.71	1.11	1.42	.83	.13	.26	1.31	1.40	1.01	.46	.22	.10
	Jun. -Sen.	--	--	.02	.04	.20	.26	.01	.09	.22	.41	.43	.34
	Grad.	--	--	--	--	.01	--	--	--	--	--	.38	.38
BUS.	Fr. -Soph.	1.33	2.09	1.45	.37	.03	--	.10	.23	.06	.03	.01	--
	Jun. -Sen.	.16	1.10	5.80	9.62	.92	.03	.01	.15	.51	.61	.08	.01
	Grad.	--	--	--	.03	7.05	3.49	--	--	--	--	.10	.07
OTHER	Fr. -Soph.	9.46	9.77	4.35	1.04	.08	.02	11.60	10.95	6.10	2.48	.53	.07
	Jun. -Sen.	.06	.46	1.61	2.29	.29	.24	.39	1.71	6.58	9.36	2.29	.91
	Grad.	--	--	--	.02	2.15	3.04	--	--	.02	.08	4.48	5.97

TABLE 2:1.4. VIII CREDIT DISTRIBUTION TABLE - FALL 1966

Average Credits Per Student [Rows Correspond to Course Classifications; Columns Correspond to Student Categories]

		ENGINEERING						NATURAL SCIENCE					
		Frsh.	Soph.	Jun.	Sen.	Mstr.	Dctr.	Frsh.	Soph.	Jun.	Sen.	Mstr.	Dctr.
EGR.	Fr. -Soph.	.98	1.74	2.53	.66	.20	.03	.19	.08	.15	.14	.05	.03
	Jun. -Sen.	.02	.70	5.81	7.79	.40	.14	.01	.12	.17	.27	.08	.01
	Grad.	--	--	.01	.21	6.01	4.68	--	--	--	.01	.04	.01
NAT. SCI.	Fr. -Soph.	7.90	7.32	1.58	.45	.10	.09	6.85	6.39	4.24	1.82	.41	.13
	Jun. -Sen.	.05	.95	3.16	2.20	2.20	.75	.09	1.37	4.92	6.38	3.62	1.14
	Grad.	--	--	.02	.04	.53	1.50	.01	.01	.10	.62	3.85	5.86
BUS.	Fr. -Soph.	.04	.11	.04	.01	.01	--	.02	.08	.04	.02	--	--
	Jun. -Sen.	--	.11	.05	.72	.08	--	--	.01	.06	.16	.01	--
	Grad.	--	--	--	.06	.08	--	--	--	--	--	.03	.02
OTHER	Fr. -Soph.	5.11	5.09	1.87	2.39	.15	.02	7.36	6.64	3.91	2.11	.12	.03
	Jun. -Sen.	.03	.14	.31	.62	.09	.06	.13	.91	1.24	1.36	.41	.08
	Grad.	--	--	--	.01	.07	--	--	--	.03	.05	.24	.07

		BUSINESS						OTHER					
		Frsh.	Soph.	Jun.	Sen.	Mstr.	Dctr.	Frsh.	Soph.	Jun.	Sen.	Mstr.	Dctr.
EGR.	Fr. -Soph.	.05	.02	.02	.02	.03	.06	.03	.06	.06	.04	.01	.02
	Jun. -Sen.	--	--	.01	.02	.02	.09	--	.01	.03	.03	.01	.02
	Grad.	--	--	--	--	.02	.09	--	--	--	--	.02	.03
NAT. SCI.	Fr. -Soph.	2.48	1.30	1.19	.76	.11	.45	1.36	1.39	1.09	.42	.20	.09
	Jun. -Sen.	--	.01	.02	.06	.18	.46	.01	.09	.30	.39	.43	.41
	Grad.	--	--	--	--	.01	.03	--	--	--	--	.34	.23
BUS.	Fr. -Soph.	1.49	2.44	1.68	.63	.05	--	.11	.28	.11	.04	.02	--
	Jun. -Sen.	.10	1.12	5.92	9.06	.63	.04	.01	.14	.54	.62	.05	--
	Grad.	--	--	.01	.05	7.56	3.78	--	--	--	.01	.16	.08
OTHER	Fr. -Soph.	9.71	9.58	4.39	1.24	.14	.06	11.94	11.21	6.28	2.62	.41	.09
	Jun. -Sen.	.11	.70	2.04	2.63	.25	.34	.35	1.68	6.39	9.29	2.05	.89
	Grad.	--	--	.01	.02	1.96	2.80	--	--	.03	.09	4.97	5.69

TABLE 2:1.4. IX CREDIT DISTRIBUTION TABLE - FALL 1967

Average Credits Per Student [Rows Correspond to Course Classifications; Columns Correspond to Student Categories]

		ENGINEERING						NATURAL SCIENCE					
		Frsh.	Soph.	Jun.	Sen.	Mstr.	Dctr.	Frsh.	Soph.	Jun.	Sen.	Mstr.	Dctr.
EGR.	Fr. -Soph.	.77	1.49	2.73	.69	.23	.02	.18	.12	.16	.12	.06	.02
	Jun. -Sen.	.05	.57	5.73	8.43	.55	.16	.01	.09	.19	.28	.02	.02
	Grad.	--	--	.01	.16	6.08	5.25	--	--	--	.02	.03	.03
NAT. SCI.	Fr. -Soph.	8.69	7.47	1.71	.36	.08	--	7.56	6.78	4.18	1.68	.68	.13
	Jun. -Sen.	.03	.73	2.51	1.53	2.23	.63	.09	.91	5.02	6.30	4.27	1.15
	Grad.	--	--	--	.06	.60	1.12	--	.01	.11	.42	2.66	5.88
BUS.	Fr. -Soph.	.04	.13	.01	.02	--	--	.02	.12	.04	.08	--	--
	Jun. -Sen.	--	.06	.21	.59	.03	.03	--	.03	.08	.13	--	--
	Grad.	--	--	--	.01	.03	.06	--	--	--	--	.01	.02
OTHER	Fr. -Soph.	4.53	5.17	1.97	2.46	.20	.12	6.61	6.64	4.06	2.01	.21	.04
	Jun. -Sen.	.02	.14	.43	.70	--	.05	.10	.98	1.05	2.44	.46	.05
	Grad.	--	--	--	.01	.08	.02	--	--	--	.05	.37	.16

		BUSINESS						OTHER					
		Frsh.	Soph.	Jun.	Sen.	Mstr.	Dctr.	Frsh.	Soph.	Jun.	Sen.	Mstr.	Dctr.
EGR.	Fr. -Soph.	.11	.08	.13	.04	.02	.02	.04	.06	.06	.04	.01	.02
	Jun. -Sen.	--	--	.01	--	--	.04	--	.02	.03	.04	--	.01
	Grad.	--	--	--	--	.01	.12	--	--	--	--	.01	.02
NAT. SCI.	Fr. -Soph.	2.93	1.48	1.56	.81	.11	.34	1.50	1.45	1.15	.47	.12	.07
	Jun. -Sen.	--	.01	.04	.05	.14	.54	.01	.07	.25	.42	.49	.45
	Grad.	--	--	--	--	--	.04	--	--	--	--	.36	.21
BUS.	Fr. -Soph.	.81	2.41	1.81	.49	.04	--	.08	.26	.10	.05	--	--
	Jun. -Sen.	.12	1.16	5.28	9.12	.50	.06	.01	.19	.58	.65	.04	--
	Grad.	--	--	--	.05	7.99	3.27	--	--	--	--	.18	.07
OTHER	Fr. -Soph.	9.11	9.03	4.07	1.09	.08	.03	11.82	11.14	6.10	2.44	.35	.12
	Jun. -Sen.	.12	.81	2.00	2.86	.18	.29	.24	1.67	6.48	9.17	2.35	1.04
	Grad.	--	--	--	.03	1.87	3.15	--	--	.01	.12	5.09	6.24

TABLE 2:1.4. X DISTRIBUTION OF NEW STUDENTS

		1964	1965	1966	1967
Total No. Entries*		13,701	15,021	14,989	14,310
Engineering	Frsh.	.0524	.0509	.0516	.0472
	Soph.	.0045	.0033	.0033	.0024
	Jun.	.0049	.0041	.0055	.0057
	Sen.	.0015	.0015	.0015	.0011
	Mstr.	.0041	.0037	.0047	.0049
	Dctr.	.0016	.0017	.0013	.0025
Nat. Science	Frsh.	.0454	.0504	.0515	.0488
	Soph.	.0054	.0040	.0044	.0035
	Jun.	.0101	.0084	.0107	.0082
	Sen.	.0159	.0049	.0047	.0057
	Mstr.	.0190	.0174	.0185	.0153
	Dctr.	.0079	.0087	.0105	.0124
Business	Frsh.	.0443	.0432	.0350	.0288
	Soph.	.0099	.0113	.0082	.0053
	Jun.	.0215	.0174	.0164	.0176
	Sen.	.0115	.0082	.0079	.0056
	Mstr.	.0229	.0205	.0295	.0262
	Dctr.	.0033	.0039	.0049	.0061
Other	Frsh.	.4038	.4311	.4074	.4182
	Soph.	.0537	.0497	.0494	.0459
	Jun.	.0728	.0689	.0662	.0741
	Sen.	.0511	.0478	.0489	.0526
	Mstr.	.1022	.1053	.1197	.1154
	Dctr.	.0404	.0339	.0385	.0463

***Including new students, transfers, and re-admitted students**

TABLE 2:1.4. XI DEPARTURE OF STUDENTS*

		1963-64	1964-65	1965-66	1966-67
Engineering	Frsh.	.15	.14	.17	.18
	Soph.	.18	.12	.15	.13
	Jun.	.12	.08	.07	.10
	Sen.	.51	.47	.40	.63
	Mstr.	.54	.50	.59	.61
	Dctr.	.38	.31	.28	.30
Nat. Science	Frsh.	.15	.17	.19	.18
	Soph.	.13	.14	.14	.15
	Jun.	.12	.15	.17	.14
	Sen.	.60	.59	.61	.67
	Mstr.	.44	.39	.42	.43
	Dctr.	.33	.33	.25	.28
Business	Frsh.	.25	.23	.24	.21
	Soph.	.22	.21	.20	.22
	Jun.	.18	.21	.18	.19
	Sen.	.73	.66	.64	.70
	Mstr.	.76	.61	.62	.60
	Dctr.	.23	.34	.35	.34
Other	Frsh.	.25	.22	.23	.26
	Soph.	.23	.21	.23	.23
	Jun.	.18	.18	.18	.17
	Sen.	.72	.70	.72	.72
	Mstr.	.54	.52	.52	.53
	Dctr.	.44	.44	.41	.42

*Entries show proportion of each category who left the university by the end of the school year (including graduates)

TABLE 2:1.4 XII PARAMETERS DESCRIBING UTILIZATION OF FACULTY EFFORT IN TEACHING*

College	1962	1963	1964	1965
Social Science	.225	.197	.205	.180
University College	.202	.183	.197	.180
Business	.285	.275	.242	.230
Education	.271	.234	.227	.266
Communication Arts	.398	.357	.321	.317
Arts and Letters	.321	.311	.337	.344
Natural Science	.336	.316	.312	.346
Agriculture	.554	.493	.455	.461
Home Economics	.499	.496	.455	.538
Veterinary Medicine	.543	.490	.484	.546
Engineering	.781	.708	.646	.663

*Entry is number of full-time equivalent faculty per student credit x 10^2.

2:1.5. The Model in Forecasting and Planning

Within the last few years, considerable effort has been devoted to computer implemented procedures for dealing with the problems of planning and future resource allocation in institutions of higher education. The purpose of these efforts is to analyze and "optimize," in some sense, the operation of the institution.

The university model provides a set of mathematical relationships among the time-functions representing the inputs, the outputs, and the internal states that can serve as the basis for formal application of optimal control and planning theory. It is unlikely, however, that mathematically described control policies can or should be applied to a social system as complex as a modern university. A more practical approach, at present, is to provide the planner or decision maker with a variety of computer programs which will allow him to explore the consequences of alternate policies in the allocation of resources.

It must be emphasized that in the development of the model, no attempt has been made to define the academic goals of higher education nor to determine optimal allocation policies nor to design decision-making procedures as such. Instead, the purpose is to provide a rational basis for evaluating alternate allocation policies under the assumption that the university has varied and perhaps conflicting goals defined by those entrusted with decision-making responsibilities.

Clearly, decisions cannot be made solely on the basis of the variables included in the model at present. The two factors of quality of education and effectiveness of alternative programs must be a part of all planning by university administrators. No one would deny that these factors are involved in education and research. Yet, few would agree on how these additional dimensions are translated to numerical measure. Therefore, unless or until quality and effectiveness can be included, the model must be regarded not as a means for administrative decision but as an aid to planning by administrators.

Since no university operates with unlimited resources, consideration must be given both to the feasibility of achieving a given set of the desired goals and to the cost of implementation. No matter how limited the goal, each planning decision affects the operation of the entire university, and the related cost can only be determined by taking into account the total pattern of resource requirements. Will additional personnel be required? Will space be diverted from some other use? What will be the total budgetary requirements? The effect of changes in the social and economic environment must also be accounted for. In addition, since the university is a dynamic institution, changing through time, the time-horizon for achieving objectives must be a factor in policy decisions. For all these reasons, it is necessary to have computer programs to process data and produce information, based on a description of the university as a total, dynamic, interrelated system.

The data presented in 2:1.4 are descriptive of the operation of the university over a period of years. If the model is to be used in forecasting and planning, it is necessary to establish first of all that the parameters obtained from present and past data are valid descriptions of future operations. Confidence in the model as a decision-making tool is developed only through tests designed to determine the extent to which the processes in question operate as the model indicates. Many of the parameter matrices reflect behavioral patterns of groups of students and collective administrative policies. If it can be established that with these matrices the model does in fact represent a reasonable approximation of the behavior of students and administrators, the model may be accepted as valid.

The problem of validation is discussed in 2:2. Closely related to the problem of validation is the problem of sensitivity, i. e. , how sensitive the behavioral characteristics of the system are to changes in the coefficients in the parameter matrices. If the model is particularly sensitive to certain parameters then, of course, special care must be taken in establishing these parameters.

If a university is operated under a fixed set of allocation policies, with unchanging degree programs and firmly controlled admissions, then validation of the model is the only prerequisite for its use in forecasting and planning. However, modern universities are, or should be, dynamic institutions, constantly adapting to changing social and economic needs, incorporating new areas of knowledge and experimenting with new educational techniques. Policy decisions are being made in one area of administration while planning is still in progress in other areas. Therefore, attempts must be made, by analysis of past operations, to anticipate the parameter changes that will occur as a result of future changes in administration. As an example, it can be assumed that a change in degree requirements in one or more departments will affect the future distribution of new students ($\underline{a}(t)$), the student transitions ($P(t)$), especially transitions from one field to another, and certainly the distribution of course credits (C). Thus, effective use of the model in forecasting and planning also requires insight into the causal relations between changes in the operation of the system and parameters changes, so that some adjustment can be made in estimated values.

Forecasting of resource requirements is based in part on accurate predictions of those demands which are not controllable by the university. If the university operates with an "open door" admissions policy, the primary source of such demands is the student sector.

Predictions of future student enrollment may be based on the student transition equation 1:3. 1. 1a, using estimated values for the transition parameters in $P(t)$, the new student distribution in $\underline{a}(t)$ and the anticipated gross number of new students, $n(t)$. Unless the student population is unusually stable, the transition matrix will vary with time, and therefore estimates based on past data must be adjusted for use in prediction. Factors in the environment of the university which affect enrollments, such as changing economic needs or "fashions" in career choice, changing birth rates, or changes in quality of students, may cause increasing or decreasing trends in the parameter values, apart from "random" variability from year to year. One suggestion for handling such trends [46] is the use of a weighted average

$$\widetilde{P}(t) = \beta_1\ P(t-1) + \beta_2\ P(t-2) + \ldots + \beta_m\ P(t-m)$$

as an estimate of $P(t)$, with $\beta_1 > \beta_2 > \ldots > \beta_m$, and $\beta_1 + \beta_2 + \ldots + \beta_m = 1$.

Keeping m and the β_i fixed, this moving - average method may be used to derive estimates $\tilde{P}(t+1)$, $\tilde{P}(t+2)$, etc., recursively.

However, the "natural trend" in transition parameters is often complicated by perturbations due to changes in university programs, changes in degree requirements, and other variations. Since the university is a dynamic and constantly changing system, the categories being used, however they may have been defined, may change in number or nature. The introduction of new departments, the consolidation of old ones, the development of new areas of study, or the founding of a new college may perturb the transition patterns in a way that defies mathematical prediction. For example, validation studies at Michigan State University have proceeded under the handicap caused by the addition of several new colleges (The College of Human Medicine and three Residential Colleges) during the time span for which machine-addressable data are available.

For these reasons, the use of the model in predicting enrollments requires anticipation of major changes in parameters. It is suggested, therefore, that statistical prediction of parameters must be supplemented by subjective evaluation by experienced university administrators of the probable effects of the types of operational changes mentioned.

Unless admissions are controlled by the administration, the parameter vector $\underline{a}(t)$ describing new student distribution must be estimated by the same techniques as P(t). However, to the extent that admissions policy can be used as a control the entries in $\underline{a}(t)$ can be determined as policy parameters.

Prediction of enrollments is somewhat more complicated if the vectors representing financial aids are introduced as controls, since estimates are required of the matrices K_1 and K_2, which describe the attraction value of the control variables (see equation 1:3.1.2a). However, if these controls are the only strong influence on enrollments, the modified transition matrix should be relatively stable compared to the unmodified matrix. In any particular university, efforts should be made to identify those factors which are affecting enrollment patterns.

The planning of future resource requirements also requires estimates of the matrices C and R, describing average student credit demands. It is also quite clear that these matrices will not remain constant over long periods. Predictions of future credit demands therefore involve both errors in the estimates of C and R and errors in the prediction of student enrollments, $\underline{s}(t)$.

Unlike the matrices of the Student Sector, the parameter matrices of the production and resource sectors represent policy parameters which are adjustable, within limits, by the administrators. For example, if the projected requirement of faculty services is not feasible in terms of availability of new staff members, it may be decided that the ratio of support facilities (such as closed circuit television) to faculty must be increased. Likewise the proportion of faculty (in contrast to graduate assistants) participating in the undergraduate teaching is, at least in part, a policy decision. Therefore, assuming for the moment that the student enrollment transition parameters discussed above have been determined to a suitable degree of accuracy (so that future demands can be predicted), efficient planning by administrators requires the capability of experimenting with alternative policy parameters. This type of experimentation is referred to as simulation and is discussed in the next section.

2:1.6 Simulation

The solution over time of the state model of the insitution, with variations in the behavioral and policy parameters and the input and control variables, establishes the time variation in the system state and other variables. When there are many variables and parameters and/or complex interrelationships, examination of all solutions may not be feasible and only selected situations are evaluated. Such solutions are called simulations. Using computer simulation, the administrator can observe the results of many years of operation, under specified policies, in a matter of minutes or hours. Therefore, simulation, even though it only approximates the real system, is a powerful tool.

The matrices in the state model of the institution are given as explicit functions of basic behavioral, policy and production matrices associated with the demand, production and resource sectors identified in the system structure. Thus, the system model is a function of behavioral, policy, and production coefficients over which there is some control and which the decision maker is free to vary in simulation experiments in an attempt to find the "best."

In each such experiment, the values of the input vectors as initial conditions and of parameter matrices of the sectors must be specified. In a fully developed simulation the parameter matrices at any given point in time are evaluated within the computer from machine-addressable master data records of the university, and provision is made for storing these parameters within the machine for later recall. Some of the initial conditions, such as faculty and environmental facilities, costs, and outside contracts, can also be evaluated at any given point in time from master records. Other variables, such as the number of entering students and their imputed values must be specified as part of the simulation experiment. It should be recognized, however, that any or all of the input variables can be varied at will to evaluate the corresponding dynamic change in the output.

Clearly, the number of meaningful simulation studies that can be made is limited only by the number of meaningful combinations of policy coefficients, terminal conditions and control conditions the administrator can put together.

Note that such simulations can establish total cost figures for the institution. For example, the scalar product of the faculty flow vector $\underline{f}(t)$ and the faculty unit cost vector $\underline{\tilde{f}}(t)$ determined from any given simulation establishes the total expenditure for faculty salary. Likewise the scalar product of $\underline{e}(t)$ and $\underline{\tilde{e}}(t)$ establishes the total expenditures for support facilities in any simulation. Further note that these expenditures depend upon the number of resource units required and their unit prices, both of which, in general, change with time as determined by the solution of the model.

The set of variables in the model classified as control variables is somewhat arbitrary. If an independent variable is to be deliberately changed with time in an effort to achieve a particular output or response, then it is usually referred to as a control variable.

A problem arises in simulating future enrollments when the student transition equation includes control variables (1:3. 1. 2a). Initial estimates of the parameters P(t) and $\underline{a}(t)$ and the number of new students, n(t), must be modified to account only for that part of the enrollment which is not attributed to the influence of financial aid. Then the effect of arbitrary changes in the value of control variables can be simulated. (See also the discussion of validation of the model, 2:2.)

When changes in the number of graduate assistantships and fellowships are simulated in an experiment, the resulting changes in total graduate enrollment will cause a change in demands for graduate credits and research teaching. For example, an increase in assistantships will increase these demands. Therefore, a simultaneous decision must be made on allocation of resources, particularly faculty effort, in the production sector. These changes will depend partly on how the increased number of graduate assistants are to be used in production. If they are to teach undergraduate courses, faculty will be available to teach graduate work. If the assistants are to be research assistants, the university must be prepared either to seek new outside contracts or to increase support of both the students and faculty in research.

Hypothetical examples of simulated changes in enrollment due to changes in the number or distribution of financial aids are exhibited in Appendix 6:1, "Systems Analysis and Planning in University Administration."

The mathematical simulations of policy decisions for situations of this type are complicated, but surely no more complicated than most administrative decision procedures.

Figure 2:1.6.I describes the simulation process.

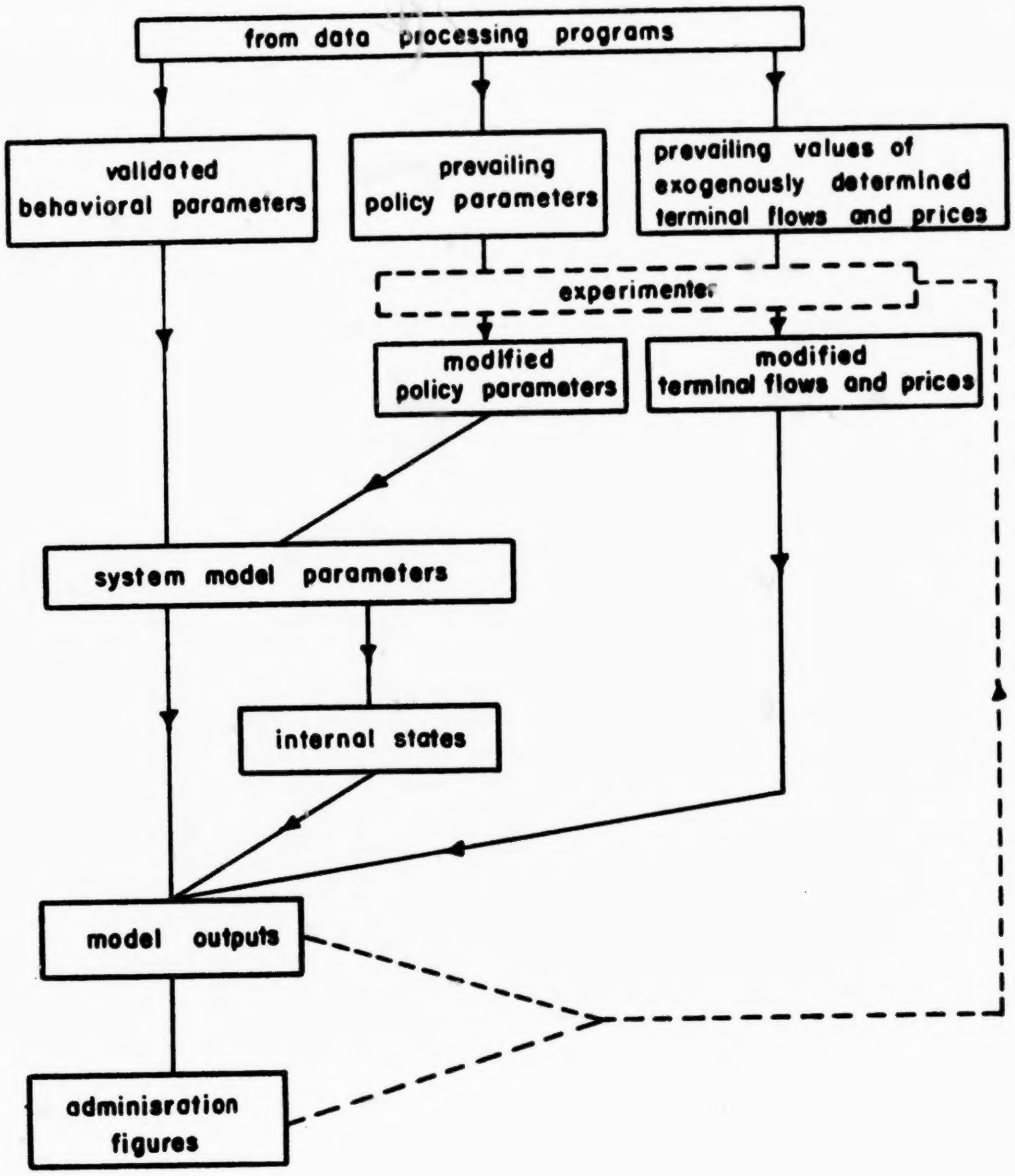

from data processing programs
validated behavioral parameters
prevailing policy parameters
prevailing values of exogenously determined terminal flows and prices
experimenter
modified policy parameters
modified terminal flows and prices
system model parameters
internal states
model outputs
adminisration figures

Figure 2:1. 6-I Logical Flow Diagram of Simulation Program for Experimenting with Alternate Policy Parameters and Controls

2:2 Validation of the Model

Confidence in a model as a decision-making tool is developed only through tests designed to determine the extent to which the processes in question operate as the model indicates. Criteria must be formulated to use in deciding whether the model is adequate, depending in part on the purpose for which the model is to be used. In any case, the most that can be asked is that a model provide a reasonable approximation to the output and resource - utilization characteristics of the institution.

The most obvious method of validation of a model is the use of historical data to simulate past performance. If the data obtained from the simulation are reasonably close to the actual data, the model is considered valid. Some of the variables in this model, such as the imputed value of education of a student leaving the university, are not really subject to validation. But if it can be established that the parameter matrices reflecting behavorial patterns of groups of students and collective administrative policies do, in fact, reasonably approximate the behavior of students and administrators, then it must be concluded that such imputed values are valid --- they represent the accumulated cost of education to a given point in time as measured by the accounting procedure implicit in the model.

Clearly, validation of a model based on historical data is not always possible. It has been pointed out previously that a model defines the data base needed for its implementation. It is unlikely that the data necessary for validation will be available when a model is being established. Simulations of past operation can, however, incorporate estimates made by experienced administrators, and their judgment of the results, if favorable, can to some extent validate the model.

If the requisite data files have been established, the problem of validating a model reduces to, essentially, a problem of determining the extent to which certain of the parameter matrices actually vary with time. It is safe to assume that none of the system parameters is fixed; all will vary with time. But there are differences in the manner in which they vary. Parameters in the education model related to resource allocation are subject to implicit or explicit manipulation by administrative decision. They are not subject to validation in the same sense as behavioral parameters. Validation of the model based on historical data thus must focus on the validation of the student sector and on determining how closely it describes the transitions in student populations and demands from year to year.

Several problems arise in validating the parameters related to student population changes. One is the fact that a relatively long set of observations of actual transition patterns must be made before any long-term trends can be determined. Secondly, since the university itself is a constantly changing system, the categories and classifications being used may change in nature or number. In that case, it will be impossible to obtain a consistent set of data. Finally, there are many factors affecting student behavior which have not been, or cannot be, incorporated into the model. Therefore, validation tests can be accurate only with some degree of error.

The adequacy of the model for prediction or simulation of future behavior depends on the accuracy of the parameter values as they pertain to the future. The values used will be based on past operating data, possibly adjusted to conform to changes in the system. The values of policy parameters for future time periods must be determined by administrators who intend to use the results of the prediction or simulation in decision making. But parameters related to population movements through the university are not subject to administrative decision, and the validity of the model as a simulation tool depends on the accuracy of the estimates of these parameters. The values used must be regarded as statistical estimates of average or expected values. The accuracy of predictions or simulations depends on the variance, or random variability, inherent in the "true" parameter values. The variances provide a measure of the probable errors in prediction, due to exogenous factors or "human inconsistency." If the variances are large, administrators must be prepared for large fluctuations from the predicted resource requirements.

In the model developed in this report, relationships between variables in each sector are linear, i.e., parameter values are simply ratios of appropriate flow measurements. The linear form is usually reasonably accurate for limited time spans and is simple in form. However, when historical data have been accumulated for long periods of time, it may be determined through data analysis that some of the functional relations are non-linear--exponential, logarithmic, or higher-degree polynomial. A further step in validation is the establishment of these relationships.

Computer-addressable data files on student enrollments are available at Michigan State University for all terms since Fall of 1963. Therefore, programs have been developed which produce data on student transitions and departures, distribution of new students, and course credit demands. It is possible to "predict" student enrollments, using the equation of the model

$$\underset{\text{future enrollment}}{\underline{s}(t)} = \underset{\text{transition parameters}}{P(t)}\,\underset{\text{present enrollment}}{\underline{s}}\,(t-1) + \underset{\text{distribution of new students}}{\underline{a}(t)}\,\underset{\text{number of new students}}{n(t)}.$$

The course credit demand data can then be used to predict credit demands:

$$\underset{\text{credit demands}}{\underline{c}(t)} = \underset{\text{credit demand parameters}}{C}\,\underset{\text{enrollment}}{\underline{s}(t)}$$

The data have been used for initial validation of the model, by comparing "predictions" of enrollment and credit demands with known historical data.

Tables 2:2.I, II, and III present the results of predictions of student enrollments of Fall terms of 1965, 1966 and 1967. In each case, student transitions were estimated from the last previous transition; distribution of new students was estimated from the previous year's distribution. Enrollments have been predicted for 20 categories of students, separated into four fields and five levels. Three of the fields are separate colleges of the university, with all other students, about 70% of the student population, aggregated as one field.

As a standard of judgment of "good" predictions, university administrators suggested that an estimate be considered "good" if it came within 10% of the actual enrollment. Based on this criterion, the model gives good predictions in 80% of the cases shown. None of the parameters were adjusted or smoothed by averaging, and some of the errors were expected because of observed variation in the parameter matrices. It was pointed out in 2:1.4 that detailed analysis of data on past operation might reveal the causes of variations in student transitions and new student distribution. Using this knowledge, parameters can be adjusted to account for anticipated changes. With these adjustments the model seems to provide a valid description of student enrollments.

Tables 2:2. IV, V and VI compare predicted student credit loads with actual load for Fall terms of 1965, 1966 and 1967. In each case, the prediction is based on the estimated student enrollment and the previous year's credit distribution table (Tables 2:1.4. V, VI, VII, VIII and IX). Therefore the prediction or estimate incorporates two sources of error: error in the estimate of student enrollment and error in the estimate of credit distribution per student. Credits have been classified by four fields, corresponding to the four fields in the enrollment estimates, and three levels: Freshman - Sophomore, Junior-Senior, and Graduate. Student credit load is computed as the average number of credits times the number of students enrolled.

The error percentages for estimated student credits are considerably larger than the percentage errors in estimated enrollments. Half of the errors are greater than 10%, almost a fourth are between 10% and 15%, and two of the 36 estimates have errors between 20% and

30%.

Some of the error may correspond to the errors in enrollment prediction. However, much of it must be attributed to variations in credit distribution from year to year. It is clear that for purposes of prediction and simulation, the credit distribution table (the matrix C of the model) must be adjusted to account for trends in student programs and for planned changes in degree requirements or course offerings. A hidden factor in these variations may be the "policies" of student advisors.

Efforts at validation of the model have been limited by the available data and by the fact that administrative personnel have not, as yet, been asked to study the problem of adjustment of parameters. As pointed out in 2:1.4, the credit distributions must be examined with aggregations at, perhaps, the department level in some cases. They must be compared with changes in student program recommendations. Errors in student credit estimates may be more closely related to errors in enrollment estimates than they appear to be at first glance, since some departments, such as the mathematics department, carry heavy service course loads for all colleges.

Despite these problems, the model thus far offers a good hope of reasonably approximating the operation of the university.

TABLE 2:2.I

PREDICTION OF TOTAL STUDENT ENROLLMENT, FALL 1965
(ESTIMATE BASED ON FALL 1963 - FALL 1964 TRANSITIONS)

Engineering	Actual	Estimate	Error	% Error
Frsh.	793	805	12	1.56
Soph.	445	520	75	16.83
Jun.	284	301	17	5.86
Sen.	385	349	-36	- 9.32
Grad.	222	216	- 6	- 2.70
Nat. Sci.	**Actual**	**Estimate**	**Error**	**% Error**
Frsh.	773	706	-67	-8.69
Soph.	504	538	34	6.83
Jun.	590	648	58	9.88
Sen.	701	711	10	1.47
Grad.	991	970	-21	-2.11
Business	**Actual**	**Estimate**	**Error**	**% Error**
Frsh.	673	688	15	2.26
Soph.	726	748	22	3.03
Jun.	905	1008	103	11.42
Sen.	1057	1149	92	8.73
Grad.	754	755	1	0.13
Other	**Actual**	**Estimate**	**Error**	**% Error**
Frsh.	6800	6335	-465	-6.84
Soph.	5497	5318	-179	-3.25
Jun.	4190	4027	-163	-3.90
Sen.	4703	4705	2	.04
Grad.	4495	4432	-63	-1.40

TABLE 2:2. II

PREDICTION OF TOTAL STUDENT ENROLLMENT, FALL 1966 (ESTIMATE BASED ON FALL 1964 - FALL 1965 TRANSITIONS)

Engineering	Actual	Estimate	Error	% Error
Frsh.	808	794	-14	-1.68
Soph.	540	480	-60	-11.19
Jun.	326	303	-23	-7.11
Sen.	377	409	32	8.46
Grad.	243	242	- 1	-0.41
Nat. Sci.	Actual	Estimate	Error	% Error
Frsh.	793	775	-18	-2.31
Soph.	572	589	17	2.90
Jun.	643	661	18	2.77
Sen.	735	751	16	2.18
Grad.	1131	1083	-48	-4.24
Business	Actual	Estimate	Error	% Error
Frsh.	549	674	125	22.71
Soph.	673	786	113	16.85
Jun.	1015	1007	-8	-0.83
Sen.	1145	1065	-80	-6.96
Grad.	979	814	-165	-16.85
Other	Actual	Estimate	Error	% Error
Frsh.	6443	6843	400	6.20
Soph.	6151	6354	203	3.31
Jun.	4864	4891	27	0.56
Sen.	5111	5153	42	0.83
Grad.	5064	4760	-308	-6.02

TABLE 2:2. III

PREDICTION OF TOTAL STUDENT ENROLLMENT, FALL 1967
(ESTIMATE BASED ON FALL 1965 - FALL 1966 TRANSITIONS)

Engineering	Actual	Estimate	Error	% Error*
Frsh.	692	773	81	11.67
Soph.	466	551	85	18.29
Jun.	380	372	-8	-2.04
Sen.	360	408	48	13.31
Grad.	263	247	-26	-6.08
Nat. Sci.	**Actual**	**Estimate**	**Error**	**% Error**
Frsh.	711	758	47	6.63
Soph.	520	580	60	11.60
Jun.	654	697	43	6.52
Sen.	787	788	1	0.10
Grad.	1152	1214	62	5.38
Business	**Actual**	**Estimate**	**Error**	**% Error**
Frsh.	432	522	90	20.91
Soph.	611	591	-20	-3.31
Jun.	1036	1007	-29	-2.75
Sen.	1130	1246	116	10.28
Grad.	1026	1059	33	3.21
Other	**Actual**	**Estimate**	**Error**	**% Error**
Frsh.	6210	6153	-57	-0.92
Soph.	5889	5916	27	0.42
Jun.	5431	5273	-158	-2.90
Sen.	5758	5684	-74	-1.29
Grad.	5327	5275	-52	-0.97

*Percent of actual enrollment

TABLE 2:2. IV

PREDICTION OF STUDENT CREDIT LOAD, FALL 1965

(BASED ON ESTIMATED ENROLLMENT AND FALL 1964 CREDIT DISTRIBUTIONS)

Engineering	Actual	Estimate	Error	% Error
Frsh. -Soph.	3,789	3,984	195	5.15
Jun. -Sen.	6,106	6,974	868	14.21
Grad.	1,473	1,466	-7	-.48
Nat. Sci.	Actual	Estimate	Error	% Error
Frsh. -Soph.	56,551	48,669	-7,882	-13.94
Jun. -Sen.	19,639	20,194	510	2.60
Grad.	7,148	5,930	-1,218	-17.04
Business	Actual	Estimate	Error	% Error
Frsh. -Soph.	6,633	8,211	1,578	23.79
Jun. -Sen.	20,432	24,226	3,794	18.56
Grad.	5,421	5,053	-368	-6.78
Other	Actual	Estimate	Error	% Error
Frsh. -Soph.	214,518	214,780	262	.12
Jun. -Sen.	86,640	94,798	8,158	9.41
Grad.	26,160	24,193	-1,967	-7.52

TABLE 2:2 V

PREDICTION OF STUDENT CREDIT LOAD, FALL 1966

(BASED ON ESTIMATED ENROLLMENT AND FALL 1965 CREDIT DISTRIBUTIONS)

Engineering	Actual	Estimate	Error	% Error
Frsh.-Soph.	4,710	3,925	-785	-16.67
Jun.-Sen.	5,930	6,848	918	15.48
Grad.	1,626	1,612	-14	-.86

Nat. Sci.	Actual	Estimate	Error	% Error
Frsh.-Soph.	61,703	53,826	-7,877	-12.77
Jun.-Sen.	21,110	20,804	-306	-1.45
Grad.	7,989	7,480	-504	-6.31

Business	Actual	Estimate	Error	% Error
Frsh.-Soph.	8,465	7,312	-1,153	-13.62
Jun.-Sen.	22,161	24,985	2,824	12.74
Grad.	7,662	5,560	-2,102	-27.43

Other	Actual	Estimate	Error	% Error
Frsh.-Soph.	232,336	234,083	1,747	.75
Jun.-Sen.	94,446	111,357	16,911	17.90
Grad.	30,875	26,449	-4,426	-14.33

TABLE 2:2 VI

PREDICTION OF STUDENT CREDIT LOAD, FALL 1967

(BASED ON ESTIMATED ENROLLMENT AND FALL 1966 CREDIT DISTRIBUTIONS)

Engineering	Actual	Estimate	Error	% Error
Frsh. -Soph.	4,720	4,819	99	2.09
Jun. -Sen.	6,144	6,901	757	12.32
Grad.	1,720	1,633	-87	-5.06
Nat. Sci.	**Actual**	**Estimate**	**Error**	**% Error**
Frsh. -Soph.	63,575	54,668	-8,907	-14.01
Jun. -Sen.	21,105	22,311	1,206	5.71
Grad.	7,917	8,364	447	5.65
Business	**Actual**	**Estimate**	**Error**	**% Error**
Frsh. -Soph.	7,425	8,244	819	11.03
Jun. -Sen.	22,761	26,592	3,831	16.83
Grad.	7,946	7,969	23	.29
Other	**Actual**	**Estimate**	**Error**	**% Error**
Frsh. -Soph.	223,776	228,606	4,830	2.16
Jun. -Sen.	104,258	117,817	13,559	13.00
Grad.	33,909	30,760	-3,149	-9.29

2:3 Implementation at Michigan State University

2:3.1 The Administrator and the Use of the Model

In developing the system model for use in allocation of resources, the systems specialist must work in close cooperation with the university administration. Most important of all, perhaps, in the "applied phase of the modeling effort, is the need to communicate to administrative personnel the purposes, uses, techniques, and limitations of the systems model in terms that do not demand a specialized technical background. The university administrator must be able to describe to the systems specialist what he would like to be able to accomplish with data processing and simulation programs, what information he wants to see, what experiments he wants to perform. Accordingly, an understanding of simulation, the structure of the model, the relationships among the variables, and the meaning of the parameters are important.

To these ends, an advisory group of Michigan State University administrative officials met informally with members of the systems project on several occasions during the development period in an effort to promote the kind of communication necessary for the practical application of the model. The nontechnical description and example simulation program included in appendices 6:1, 6:2, and 6:3 were designed specifically as instruments of communication. The written description, "Systems Analysis and Planning in University Administration," (6:1) includes a brief, non-mathematical discussion of the model itself and the reasons for its development. Following this is a description of a hypothetical university, with its 13,879 students categorized into two fields (Science and Humanities) and two levels (undergraduate and graduate). Using artificial but reasonable parameters, all data contained in the equations of the student sector and academic production sector are presented in the form of easy-to-read tables. Budget figures are included, and average unit costs of education for each of the four student categories are developed. Also included are tables which "simulate" the effects of varying the distribution of fellowships and scholarships.

The example simulation program, "A Prototype Planning and Resource Allocation Program for Higher Education," (6:3) is written for use on a time-sharing computer system. This program has proven to be very effective in demonstrating the objectives of the simulation when presented as an operating program (rather than as a document) at a teletypewriter terminal. It can be used to simulate the effects of various administrative decisions in a hypothetical university having two fields and two levels. Artificial data are stored. The user may call for a print-out of various stored data and computed operating costs; he may then enter various changes in operation policy and variables and call for a print-out of variables under the changed conditions. Although the program is limited in size and scope, it provides ample opportunity for the university administrator to "learn" about simulation in a framework of operation in which he can react immediately to the machine output.

Experience suggests that a relatively simple example of this type should be a permanent part of any extensive battery of data processing and simulation programs prepared for administrative use.

2:3.2 Enrollment Analysis

It has already been indicated that certain parts of the model may be used in a variety of ways to answer questions pertaining to limited aspects of the system. The following study carried out in the College of Engineering by the Office of Student Affairs is typical of such applications.

The College was asked to determine the "optimal" number of admissions by departments and level for the forthcoming academic year, subject to the constraints that the number of faculty and staff positions are to remain fixed and there is to be no increase in physical facilities.

The answer to such a question involves many dimensions. First of all, there is the question of what is "optimal", and secondly there is the question of the mechanics of realizing that optimality. The question of what is optimal is certainly subjective and outside the scope of direct solution by the model. However, the following questions, related to the mechanics of realizing any given level of enrollment, are very much within the scope of the model:

1. What are the attraction and retention rates of students entering the College at the various levels and how do these rates compare to other colleges in the university?
2. What are these attraction and retention rates for Michigan students in contrast to out-of-state students?
3. What are the transfer rates and retention rates in Engineering by department and level in relation to

other department enrollments?

4. What is the pattern of course selection of students within the College by field and level?

The student transition table and credit demand table provide an answer to these questions. The question as to the "optimal" enrollment level depends upon the subjective evaluation of the "quality" of education resulting from a variety of possible educational methods that might be employed. A subjective measure of the quality of the incoming students and the associated educational program can perhaps be inferred by superimposing on the results of the simulation the gradepoint averages of the students moving into and out of engineering.

2:3.3 A Simulation

Although a data base for a complete parameterization of the model is not currently available, a simulation of the College of Engineering in relation to the remaining colleges in the university has been realized. The details of the data base and the simulation are given in 4:5.3.

2:4 Identification of Controls: A Study of the Influence of Financial Aids on Graduate Enrollments

There is almost unanimous agreement among educators that offers of financial aids, such as fellowships, scholarships, and teaching or research assistantships, will attract students to a university, at the graduate level in particular. Therefore, financial aids are included in the university model as a "control" variable, with the assumption that the influence of financial aids on enrollment can be measured and described mathematically. It can also be assumed that factors such as curriculum, faculty reputation, location, and educational facilities affect a student's choice of a university and that the effectiveness of financial inducements is enhanced or modified according to a student's perception of them.

In an effort to measure the influence of financial aids and other variables on graduate enrollments, a survey was designed to determine what factors are considered most important by graduate students in choosing a university. The objective of this survey, conducted as part of larger study in marketing*, was, specifically, to find out why some people "buy" the educational services of Michigan State University (i. e., enroll), while others prefer not to "buy" the same services (i. e., choose not to enroll). The survey sample therefore includes both students who attended the university during the 1967-68 school year and students who were accepted for admission to graduate study in Fall, 1967, but who chose not to enroll. These groups are referred to respectively as "shows" and "no-shows". The "shows" include seniors as well as graduate students in order to assess the opinions of undergraduates who might be considering graduate school in the near future.

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*This study forms part of a Ph. D. dissertation by G. N. Naidu, Michigan State University College of Business [89].

In this initial survey, all types of financial aid are aggregated. Students are separated into four field categories: Business, Engineering, Social Science, and all others. Details of the sampling plan are contained in Supplement 4:1.

Two questionnaires were designed, one for "shows" and one for "no-shows", to obtain all relevant information, such as the student's perception of Michigan State University, perception of a comparable university, factors which influenced the decision to attend or not attend, and available alternatives at the time of decision. In an attempt to measure the influence of financial aids, students who attended M. S. U. and who received fellowships, assistantships or other aid were asked the probability they would not be in attendance without the aid. Questions were also included to obtain socio-economic and demographic information, parent's education, draft classification, and career expectations. These questionnaires are reproduced in Supplement 4:1. They were mailed to all students in the sample, with an over-all response of 62%

The survey shows that financial aids are without doubt a determining factor in a student's decision about graduate school. However, it also shows that money alone cannot attract high-quality graduate students who are also seeking a good curriculum and an equally good faculty. Table 2:4-III presents the average probability, by field and level, that a student receiving financial aid would not be attending Michigan State University without the aid. Table 2:4-IV gives the "attraction value" of a unit of financial aid in each category. These data take into account the number of students enrolled without financial aid of any type (for whom the probability of attending without aid is assumed to be 1.0), as well as the probabilities displayed in Table 2:4-III. The entries in Table 2:4-IV may be interpreted as the proportions of total enrollment attributable to financial aid. A unit of financial aid is taken to be any fellowship, scholarship, grant, or assistantship awarded to an individual. Loans were not regarded as financial aid in the sense of this survey.

It is estimated on the basis of survey returns that about 84% of the "no-shows" are attending some other university. However, this estimate may be biased, since a high proportion of those not responding may be in military service.

In the questionnaires, students are asked to rank, in order of importance, the factors which most influenced their graduate school plans. Analysis of the data indicates that both "shows" and "no-shows" consider curriculum in the major field, faculty reputation in the major field, financial aid available, and general reputation of the university as four of the five most important factors determining the choice of a school. However, the groups differ significantly in the magnitude of importance given to the first three of these factors. The "no-shows" give considerably more weight to curriculum, faculty reputation, and financial aids, and also consider educational facilities (library, computers, etc.) among the five most important factors. The "shows", on the other hand, place more stress on location (nearness to home).

With respect to perception of the availability of financial aid, "no-shows" rate Michigan State significantly lower when compared to some other university with which they are familiar. Of this group, 45.8% received similar or better offers of financial aid elsewhere, whereas only 13.3% of the "shows" reported similar or better offers.

Table 2:4-I Number of Students Enrolled, Fall 1967

	Engineering	Business	Social Science	Other
Senior	398	991	1514	4303
Master	116	646	418	2791
Doctoral	149	255	384	2240

Table 2:4-II Number of Students Receiving Financial Aid

	Engineering	Business	Social Science	Other
Senior	106	108	250	839
Master	39	312	249	973
Doctoral	105	176	277	1528

Table 2:4 - III Average Probability That a Student Receiving Financial Aid Would be Attending M. S. U. Without the Aid

	Engineering	Business	Social Science	Other
Senior	.621	.688	.657	.678
Master	.497	.698*	.528	.459
Doctoral	.284	.423	.507	.429

*The Masters program in Business Administration enrolls many business executives returning to college for advanced studies.

Table 2:4 - IV Proportion of Total Enrollment Attributed to the Influence of Financial Aids*

	Engineering	Business	Social Science	Other
Senior	.101	.034	.057	.063
Master	.169	.146	.281	.189
Doctoral	.504	.398	.356	.389

*These figures take into account the number of students attending without financial aid and the fact that financial aid is only partly responsible for the presence of those receiving aid.

Of the "no-shows", 8.9% received offers that were less than M.S.U.'s but preferred another university because of better academic reputation, or convenience.

It is significant that "no-shows" who were offered financial aid by Michigan State had, on the average, 2.1 other offers, whereas the "shows" receiving aid averaged only 0.5 other offers. The "no-shows" have slightly higher undergraduate grade-point averages and report slightly higher parental income.

Further analysis shows differences in the importance of curriculum, faculty, and financial aid when students are separated by field of study. For example, Engineering students give significantly higher importance to financial aid obtained from the university than do students in other fields, as determined by the subjective probabilities in Table 2:4-III.

Details of the survey and analyses of the data are included in Supplement 4:1. Further analysis and discussion of the marketing aspects of graduate education may be found in [89].

This pilot survey indicates the feasibility of including financial aids in the model as a control variable. In order to do so, parameters such as those in Table 2:4-III must be obtained separately for new students in each field-level category and for each of the transition groups defined by the student transition table (the matrix P(t) of the model). In addition, the data must be obtained separately for fellowships, scholarships, assistantships, and other aids. In the survey reported here, it was necessary to aggregate categories of students and types of aid to obtain reasonable sample sizes and because of limitations in personnel and time.

The sample survey method is impractical if data on the influence of financial aid is to be included as part of the data base for the implementation of the model. Instead, information for rapid machine processing must be obtained, perhaps during registration, from each student receiving financial aid in some form. If this information is included as part of the permanent student record (see 2:1.2, 3:1) the parameters can be updated regularly. The exact nature of the information to be obtained requires further study. Clearly, such things as the number of alternatives available to students who chose this university are indicators of the "attraction value" of financial aid. In addition, the student's perception of the quality of education must be taken into account.

Part 3

COMPUTER IMPLEMENTATION OF THE MODEL

3: COMPUTER IMPLEMENTATION OF THE MODEL

Several aspects of the developments necessary to implement the model have been realized using Michigan State University files and records. However, it must be clearly understood that though many of the data used in the implementation of the model have been determined from Michigan State University records, the parameters derived from these records may not be consistent. Of necessity, data were taken from diverse sources, different years, and in some cases are only gross estimates. Consequently no conclusions should be drawn about Michigan State University or its operations from the examples presented here. The results are presented for demonstration purposes only and at best indicate orders of magnitude.

The developments reported here include techniques for using existing records, development of specifications for new records, computer programs for simulating some components of the system in considerable detail, and programs for simulating the whole system in aggregate. Actual use has been made by some administrators of certain programs; other programs have been used to demonstrate potential uses of the model through simulation.

For the most part applications of these programs are presented in other parts of this report. The description of the data files are presented here as Part 3, while the programs themselves are found in Part 4.

The structure of the model identifies specifically the additional records and refinement in existing records required for effective implementation. Data requirements beyond files currently available include (1) more detailed information on faculty, (2) better information on incoming students and (3) identification of factors that influence enrollment choices in various subject areas along with a measure of the magnitude of these influences.

Ultimately complete implementation requires a central integrated acquisition and retrieval system wherein all resources and other flows are measured in the same units, collected and updated at the same time and, preferably, readily available in computer-usable form. Missing data, data from different sources each with its own filing and coding system, inconsistency in the time of acquiring or updating, and other problems associated with a decentralized system must be avoided if the model is to assume a routine position in management and planning.

Many institutions, including Michigan State University, currently maintain machine records on various aspects of the total system that are almost ideally suited for deriving parameters for the model. Three such files at Michigan State University are the Student Master Record, the Class Card Record and the Faculty Class Schedule Record generated each school term, used and modified during that term, then saved to become a part of the University historical record.

3:1 Data Files Available at Michigan State University

Fig. 3:1-I lists the tape file that has been used and indicates the scope of records that are currently available. The contents of these data files are detailed in the following sections.

Though records are actually kept and processed by the University Data Processing Department, the files indicated in Fig. 3:1-I have been rewritten for use under the CDC 3600 Drum Scope System. Details for use of that system are available from the Computer Laboratory Library but some information is given here to illustrate the way control over the data files is maintained.

The system requires each tape to be labeled, through which security, verification and accounting can be accomplished, or to have a blank label (unlabeled). These labels and the associated System EQUIP cards are described in Fig. 3:1-II.

3:1.1 Student Master File

The Student Master File is updated each term and contains one record for each student with some 70 items of information as indicated in Fig. 3:1-III. Included for each student and of particular interest in the implementation thus far are a student identification number, curriculum major, class level, credits earned to date and admission code.

These records are each 400 BCD characters in length terminated by the BCD character] (octal 72), called a record mark. Three of these student records are assembled into one physical record (1203

Tape No.	Type	Term	Label (** = unlabeled)
6	Student Master	Fall 65	**(2 of 2)
13	Student Master	Winter 64	(W 64 STU MAST, 1, 1, 999)
14	Student Master	Spring 64	(S 64 STU MAST, 1, 1, 999)
15	Student Master	Spring 65	(S 65 STU MAST, 1, 1, 999)
16	Project Tape		(DATA TAPE 2, 1, 1, 999)
17	Student Master	Winter 65	(W 65 STU MAST, 1, 1, 999)
51			
52	Sorted Faculty by Cl.	Fall 62	(F 62 SO-FAC-CL, 1, 1, 999)
423	Project Tape		(STUVEC, 1, 1, 999)
424	Student Master	Fall 65	** (1 of 2)
425	Clascard W/O Grades	Fall 64	**
426	Student Master	Fall 64	** (2 of 2)
427	Clascard W/O Grades	Fall 65	**
428	Student Master	Fall 64	** (1 of 2)
429	Clascard W/O Grades	Fall 63	**
430	Student Master	Fall 66	** (1 of 2)
523	MIDAS		(MIDAS, 1, 1, 999)
524	Clascard W/O Grades	Fall 66	**
525	Student Master	Fall 63	**
526	Project Tape		(DATA TAPE 3, 1, 1, 999)
527			
528			
529	Student Master	Fall 66	** (2 of 2)
530	Student Master	Fall 67	** (3 of 3)
538	Project Tape		(BACK-UP TAPE 1, 1, 1, 999)
539	Project Tape		(MSUSIM2 ABS, 1, 1, 999)
804	Clascard W/O Grades	Spring 65	(S 65 CL-CRD, 1, 1, 999)
805	Clascard W/O Grades	Winter 65	(W 65 CL-CRD, 1, 1, 999)
806	Project Tape		(DATA TAPE 1, 1, 1, 999)
807	Clascard W/O Grades	Spring 65	(S 65 CL-CRD-GR, 1, 1, 999)
821	Student Master	Fall 67	** (1 of 3)
822	Student Master	Fall 67	** (2 of 3)
823	Bump		(BUMP, 1, 1, 999)
824	Project Tape		(DATA TAPE 2, 2, 1, 999)
825	Bump		(BUMP, 2, 1, 999)
828	Infol Tape		(BIBLIOGRAPHY, 1, 1, 999)
829	Infol Tape		(BIBLIOGRAPHY, 2, 1, 999)
830	Project Tape		(DATA TAPE 3, 1, 1, 999)
831	Project Tape		(DATA TAPE 3, 2, 1, 999)
832	Clascard W/O Grades	Fall 67	**

Fig. 3:1-I Project Tape File (7-15-68)

MAGNETIC TAPE LABEL FORMAT

Magnetic tapes are labeled using the following format, with everything written in BCD mode, 2 octal digits per character, 80 characters per label:

Character	Use	Contents of the field
1	Tape density	5 (HI Density tape)
2-3	Unique label identifiers	( )
4-5	Logical unit number	(Intentionally blank)
6-8	Retention code	999 (permanent retention)
9-22	Identification	

The identification label is a 14-character field (including blanks) which will identify a tape. Each type of tape will have a general type of label.

23-24	Reel number	01 (02 for cont. reel)
25-30	Date written	Supplied automatically
31-32	Edition number	01
33-40	Physical identification	XXX (trailing blanks)

Where XXX is the tape number

41-48	PNC number	520639 (trailing blanks)
49-80	User supplied information	

IDENTIFICATION LABELS

STUDENT MASTER TAPES

X↑ YY↑ STU↑MAST

X is the term, F-Fall, W-Winter, S-Spring, U-Summer
YY is the last two digits of the year

CLASS CARDS WITHOUT GRADES

X↑ Y↑↑CL-CRD↑↑↑

CLASS CARDS WITH GRADES

X↑YY↑ CL-CRD-GR

SORTED FACULTY CLASS

X↑ YY↑ SO-FAC-CL

EQUIP CARD FORMATS

UNLABELED TAPES

$^{7}_{9}$ Equip, XX=HI, RO, **, MT(YY, W)
Where XX is the unit number of the tape to be read.
YY is the physical number, W is a continuation reel, if one is needed. (See below)
$^{7}_{9}$ stands for $^{7}_{9}$ control card.

LABELED TAPES

$^{7}_{9}$ Equip, XX=HI, RO, (ZZ, 01, 01, 999), MT(YY)
Where ZZ is the identification label. (See below.)

Fig. 3:1-II

characters). The last physical record on the tape may be padded with records, each character of which is a nine, if the number of students is not a multiple of three.

Following the last physical record is an IBM end-of-file mark (octal 17). It should be noted that this is not a CDC end-of-file and will not be treated as such. However, in the relabeling process a SCOPE tape label is placed on the tape as well as a CDC end-of-file mark at the end.

A program (STUVEC) for processing this file, as used in this implementation, is described in 4:3. and an example of the output is shown in Table 2:1.4 I.

3:1.2 Class Card File

The Class Card is illustrated in Fig. 3:1-V and the contents of the card is indicated in Fig. 3:1-VI. One such card exists for each class attended by each student and also serves as a grade card at the end of the term.

The Class Card tapes are written with 20 Class Cards per physical record. A Class Card may be either 80 columns or 68 columns depending on whether the grade is on the card or not.

(This file is assembled at registration and used for current term information and, of course, grades are unearned at this time. When grades are submitted,a new file with the additional information is collected and a copy of each is retained in the historical record.)

Following each Class Card is a record mark. This results in either a 1620 character record or a 1380 character record. As in the student master tapes, if there are not enough Class Cards to fill the last physical record, additional records having a nine for each character are used to pad it out. The tape ends with an IBM end-of-file mark. After relabeling, the tape contains the new label and the CDC end-of-file.

From this record, field-level loadings are ascertained as a function of the student field-level category. A program (CLASCARD) for processing this file is described in 4:4 and an example of the output obtained will be found in Table 2:1. 4 V.

3:1. 3 Faculty Class Schedule

The Faculty Class Schedule record in Fig. 3:1 VII consists of a pair of cards associating each faculty member with the courses taught by him. This record could be utilized to associate the rank of the instructor with the courses taught, but this refinement has not been utilized in the current implementations.

A listing of a processing program (FACCLS) for this data is bound separately with other computer material for the sake of completeness, but it is not documented nor has it been used extensively.

STUDENT MASTER RECORD FORMAT AS OF JANUARY 15, 1964
(400 CHARACTER RECORD)

DATA FIELD	CHARACTERS
LEVEL	1
CURRICULUM	2-3
CLASS	4
STUDENT NUMBER	5-10
STUDENT NAME	11-29
SEX AND MARITAL STATUS	30
RESIDENCE CODE	31-33
DATE OF BIRTH	34-39
ENTRANCE RECORD	40-52
ADMISSIONS CODE	53
LAST SCHOOL ATTENDED-CODED	54-60
HIGH SCHOOL QUARTILE RANK	61
ADVANCE PAYMENT	62
ACADEMIC ADVISOR NUMBER	63-65
CLASSIFICATION	66
MAJOR CODE	68-69
OFF CAMPUS	70
YEAR OF COMPREHENSIVE EXAM TERM	72-73
SOCIAL SECURITY NUMBER	81-89
CREDITS ENROLLED PREVIOUS TERM	100-101
CREDITS CARRIED PREVIOUS TERM	102-103
CREDITS EARNED PREVIOUS TERM	104-105
POINTS EARNED PREVIOUS TERM	106-107
GPA PREVIOUS TERM	108-110
TRANSFER CREDITS	111-113
TOTAL CREDITS CARRIED-MSU	114-116
TOTAL CREDITS EARNED-MSU	117-119
TOTAL POINTS EARNED-MSU	120-123
MSU GRADE POINT AVERAGE	124-126
MSU TOTAL POINTS BELOW C	127-128
REPEAT CREDITS CARRIED	129-130
REPEAT CREDITS EARNED	131-132
REPEAT GRADE POINTS	133-134
REPEAT POINTS BELOW C	135-136
TOTAL REPEAT CREDITS	137-138
ORIENTATION TEST ENGLISH	139-140
ORIENTATION TEST READING	141-142
ORIENTATION TEST ARITHMETIC	143-144
ORIENTATION TEST MATH	145-146
COLLEGE QUALIFYING TEST-VERBAL	147-148
COLLEGE QUALIFYING TEST-INFORMATION	149-150
COLLEGE QUALIFYING TEST-NUMERICAL	151-152
COLLEGE QUALIFYING TEST-SUM	153-155
DORM ABBREVIATION	156-158

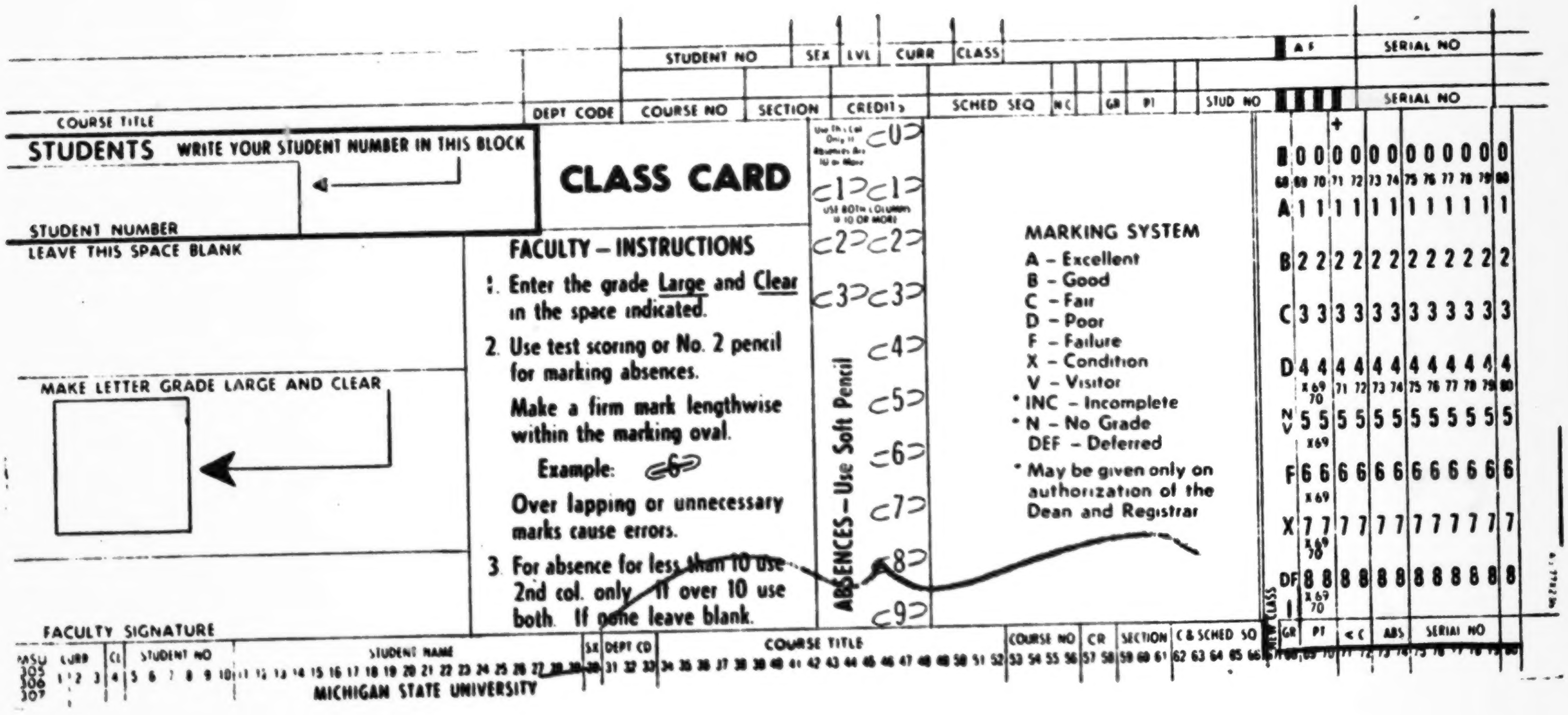
HOUSING CODE	159
DORM AND PRECINCT CODE	160-163
LOCAL STREET AND NUMBER	164-182
LOCAL CITY AND STATE	183-201
LOCAL PHONE	202-208
GRADE REPORT NAME	209-227
STREET AND NUMBER	228-246
GRADE REPORT CITY, STATE AND ZIP CODE	247-270
PARENTS NAME	271-289
PARENTS STREET AND NUMBER	290-308
PARENTS CITY, STATE AND ZIP CODE	309-332
ATHLETE SPORT CODE	333-334
PROBATION CODE	335
DEGREE CODE	336
HONORS COLLEGE CODE	337
SOCIETY CODE	338-340
TERM OF FIRST REGISTRATION	341-345
PREVIOUS RESIDENCE CODE	346-348
PARENT-SELF-GUARDIAN CODE	349
POINTS EARNED PREVIOUS TERM	350
PREVIOUS CLASS	351
PROJECTED CLASS	352
TOTAL REPEAT POINTS	353-356
SELECTIVE SERVICE NUMBER	357-367
SERIAL NUMBER	396-400

CHARACTER POSITIONS 368 THRU 395 ARE OPEN FOR ADDITIONAL INFORMATION-------

Fig. 3:1-III

INFORMATION	STUDENT 1		STUDENT 2		STUDENT 3	
	WORD	CHARACTER	WORD	CHARACTER	WORD	CHARACTER
STUDENT NUMBER	1	5-8	51	6-8	101	7-8
	2	1-2	52	1-3	102	1-4
CLASS	1	4	51	5	101	6
See Student Directory - Older directories available in Administration Building						
CURRICULUM	1	2-3	51	3-4	101	4-5
University-defined alphanumeric codes						
CLASSIFICATION (Admission Status)	9	2	59	3	109	4
1 New Undergraduate						
2 Transfer Undergraduate						
3 New Master Candidate						
4 Transfer Master Candidate						
5 New Doctoral Candidate						
6 Transfer Doctoral Candidate						
7 Special Student						
ADMISSIONS CODE (Present Status)	7	5	57	6	107	7
Returning Student						
T First Time Student						
2 Re-enrolled Student						
3 Returning Student, With Level Change						
TOTAL CREDITS	15	5-7	65	6-8	115	7-8
					116	1

Fig. 3:1-IV Student Master Physical Record Format



STUDENT NO | SEX | LVL | CURR | CLASS | A F | SERIAL NO

COURSE TITLE | DEPT CODE | COURSE NO | SECTION | CREDITS | SCHED SEQ | NC | GR | PI | STUD NO | SERIAL NO

STUDENTS WRITE YOUR STUDENT NUMBER IN THIS BLOCK

STUDENT NUMBER

LEAVE THIS SPACE BLANK

CLASS CARD

FACULTY – INSTRUCTIONS

1. Enter the grade Large and Clear in the space indicated.
2. Use test scoring or No. 2 pencil for marking absences.

   Make a firm mark lengthwise within the marking oval.

   Example: ⊂6⊃

   Over lapping or unnecessary marks cause errors.
3. For absence for less than 10 use 2nd col. only. If over 10 use both. If none leave blank.

MAKE LETTER GRADE LARGE AND CLEAR

FACULTY SIGNATURE

ABSENCES – Use Soft Pencil

Use This Col Only If Absences Are 10 or More

USE BOTH COLUMNS IF 10 OR MORE

⊂0⊃ ⊂1⊃⊂1⊃ ⊂2⊃⊂2⊃ ⊂3⊃⊂3⊃ ⊂4⊃ ⊂5⊃ ⊂6⊃ ⊂7⊃ ⊂8⊃ ⊂9⊃

MARKING SYSTEM

A – Excellent
B – Good
C – Fair
D – Poor
F – Failure
X – Condition
V – Visitor
* INC – Incomplete
* N – No Grade
DEF – Deferred

* May be given only on authorization of the Dean and Registrar

MSU 305 306 307 | CURR 1 2 3 | CL 4 | STUDENT NO 5 6 7 8 9 10 | STUDENT NAME 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 | SX 30 | DEPT CD 31 32 33 | COURSE TITLE 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 | COURSE NO 53 54 55 56 | CR 57 58 | SECTION 59 60 61 | C & SCHED SQ 62 63 64 65 66 | NEW CLASS | GR | PT | < C | ABS | SERIAL NO

MICHIGAN STATE UNIVERSITY

Fig. 3:1-V

CLASS CARD FORMAT

Field	Characters
Curriculum	1-3
Class	4
Student Number	5-10
Student Name	11-29
Sex and Marital Status	30
Department Code	31-33
Course Title	34-52
Course Number	53-56
Credits	57-58
Section	59-61
C and Schedule Sequence Number	62-66
New Class	67
Grade	68
Points	69-70
Points below C	71-72
Absences	73-74
Serial Number	75-79
Blank	80

Fig. 3:1-VI

FACULTY CLASS SCHEDULE RECORD FORMAT

Faculty Card

Field	Character
Blank	1-28
Rank Code	29
Blank	30-39
Number of months work	40-41
Salary	42-46
% of time spent working	47-49
% of time in the general department	50-52
% of time spent instructing	53-55
Blank	56-70
Identification Number	71-79
Blank	80

Course Card

Field	Character
Blank	1-45
Total enrollment	46-49
Alphabetic department code	50-52
Course Number	53-56
Blank	57-70
Instructor identification number	71-79
Blank	80

Fig. 3:1-VII

3:2 Programs for Processing Data Files

The Student Master Tapes have been processed by the program STUVEC described in the supplement, 4:3, to yield some of the parameters of the model including the student transition matrix, distribution of new, transfer, and re-enrolled students, and the output vectors for dropped and graduated students.

The Class Card Tapes, using the program CLASCARD, have been processed to develop the credit distribution matrix. This program is described in the supplement, 4:4.

Data files, such as those indicated above, are of course both school-dependent and machine-dependent; that is,the format will be different from one school to the next and will also depend on the computer system that is used to maintain the files. This implies, of course, that other systems require different programs as counterparts to STUVEC and CLASCARD. Also, since the files are machine-dependent, more efficient programs can usually be written in assembly language (machine-dependent) than in some higher level language. Two versions of the programs described have been maintained. In the interest of transferability as well as preserving compatibility as computer systems are changed within a given school, the programs have been written in FORTRAN. These versions are presented in the supplement. However, to increase the operating efficiency of these programs in actual use, assembly language (machine-dependent) versions have been utilized in some parts.

3:3 Computer Programs Based on the Model

Several programs based on the system equations presented in Part I have been developed. They range from an early program to investigate the feasibility of computer implementation through a demonstration program to one which gives the user considerable flexibility in designing experiments and which incorporates several sectors of the theoretical model. It is oriented to the university department operating accountings for faculty, staff, supplies and services, and equipment.

The support data and processing programs are discussed in the supplement, 4:5. In this section, the implementation details are presented, including a user's manual for the one which has received the major implementation effort over the past year.

Part 4

SUPPLEMENTS

4:1 A Survey to Establish Parameters Describing the Influence of Financial Aids

prepared by

G. M. Naidu
R. Zemach

4:1 Survey on the Influence of Financial Aids

The following is a detailed description of the survey given in 2:4.

Sampling Plan

The population of "no-shows" consists of those who were granted admission to Michigan State University for graduate study in Fall 1967 and who did not attend a graduate school or went to some other university. This group includes former Michigan State University students who did not return.

No. of Applicants	7,444
No. Accepted	4,838
No. Attending MSU	2,074
No. of "No-Shows"	2,764

Among the "no-shows" were 680 who had been selected to receive financial aid at Michigan State University, if they had attended.

Because of limitations on access to university files, a systematic sampling method was used. Allocation of sample size was based on practical considerations in order to obtain a large enough response from each category of the population for meaningful comparisons. As a result, some of the categories are measured with greater precision than others. Table 4:1-I presents details of the sampling distribution.

The population of "shows" includes seniors, master and doctoral candidates on campus during the 1967-68 school year. The total sample was allocated according to level, degree category, and college, as shown in Table 4:1-II. The required sample was drawn randomly. Out of 1269 questionnaires mailed to "shows," 36 were returned undelivered. Substitutes were chosen from the corresponding strata to complete the sample.

Table 4:1 -I Sampling Distribution of No-shows

College	Sample of Students Admitted Without Aid	Sample of Students Admitted With Aid	Total
Business	72	55	127
Engineering	16	47	63
Social Science	64	74	138
Other	236	115	351
Total	388*	291	679

*The actual sample included 451. Of these 35 foreign students were omitted, and 28 questionnaires were returned undelivered.

Table 4:1-II Total Enrollment and Sample Sizes for Students Attending Michigan State University

College	Seniors				Masters				Doctoral			
	Aid		No aid		Aid		No aid		Aid		No aid	
	Total	Sample	Total	Sample	Total	Sample	Total	Sample	Total	Sample	Total	Sample
Bus.	108	50	883	55	312	50	334	50	176	55	79	50
Engr.	106	40	292	45	39	39	77	45	105	50	44	40
Soc. Sci.	250	55	1264	60	249	55	169	50	277	60	107	55
Other	839	55	3464	65	973	60	1818	60	1528	85	762	35
Total	1303	205	5903	225	1573	204	2398	205	2086	250	992	180
Sample Sizes	430				409				430			

Total Sample = 1269

The questionnaires at the conclusion of this section were mailed to both groups, accompanied by the letters requesting that the questionnaires be returned as soon as possible. A follow-up letter was sent 15 days later to all "no-shows". The "shows" were contacted by telephone. The response obtained is summarized below.

	Total Sample	Response
Shows	1269	63.8%
No-shows	679	59.0%

Seven responses, 4 "shows" and 3 "no-shows", arrived too late to be included in the initial analysis of the data.

Analysis

Table 4:1-III summarizes the response concerning the importance of factors affecting students' decisions to attend or not attend Michigan State University. The analysis used is a Chi-squared test of independence. The difference between "shows" and "no-shows" is highly significant for five of the six factors.

Other details related to the importance of financial aid are contained in 2:4.

Table 4:1-III Relative Importance of Factors Affecting a Choice of University

(Students were asked to rank the five most important factors, with number 1 as the most influential and 5 as the least influential.)

A. Curriculum in the Major Field

	Rank 1	2	3	4	5	Not included	Total
No-shows	149	104	61	25	14	42	395
Shows	171	116	81	43	39	100	550*

*Graduate students only

Chi-square = 20.356 (significant at 1% level)

B. Faculty Reputation in the Major Field

	Rank 1	2	3	4	5	Not included	Total
No-shows	85	119	75	33	13	70	395
Shows	88	130	91	55	32	154	550

Chi-square = 22.625 (significant at 1% level)

C. General Reputation of the University

	Rank 1	2	3	4	5	Not included	Total
No-shows	40	47	81	69	51	107	395
Shows	56	71	127	78	66	152	550

Chi-square = 2.66

Table 4:1 - III (continued)

D. Financial Aid Offered

	Rank 1	2	3	4	5	Not included	Total
No-shows	78	61	70	70	28	88	395
Shows	78	44	48	44	36	300	550

Chi-square = 107.08 (significant at 1% level)

E. Educational Facilities

	Rank 1	2	3	4	5	Not included	Total
No-shows	3	10	30	76	75	201	395
Shows	11	28	35	85	66	325	550

Chi-square = 18.88 (significant at 1% level)

F. Location of Campus

	Rank 1	2	3	4	5	Not included	Total
No-shows	9	8	8	25	71	274	395
Shows	56	44	34	47	56	313	550

Chi-square = 62.342 (significant at 1% level)

MICHIGAN STATE UNIVERSITY EAST LANSING · MICHIGAN 48823

COLLEGE OF ENGINEERING · ENGINEERING BUILDING

April 15, 1968

To: (Graduate Applicants Not Attending MSU)

As part of a research program sponsored by the National Science Foundation, Office of Education and Manpower Studies we are conducting an in depth study of the decisions made by graduates in selecting their graduate schools. This information will be used in an effort to determine the influence of various financial aid programs on graduate enrollments and in an effort to model, mathematically, certain aspects of the university business operation.

You are one of a group of persons known to have been admitted to Michigan State University, but did not choose to attend during the Fall term 1967. We hope that you will be willing to take time to give us insight into the factors that contributed to this decision by completing the enclosed questionnaire. We would like for you to be as frank as you possibly can. Your answers will remain anonymous. A postage paid envelope is enclosed for your convenience in returning the completed questionnaire.

We thank you in advance for your cooperation. Your cooperation will help us answer questions that are of direct concern to the institutions of higher education.

Sincerely,

H E Koenig

H. E. Koenig, Director
Systems Science Program

HEK:nab

SURVEY OF GRADUATE APPLICANTS (FALL 1967) AT MSU

Systems Science Group
Division of Engineering Research
Michigan State University

1. Did you attend a college/university during Fall, 1967? (CHECK ONE)

   a) Yes

   b) No (if 'no' go to 5)

2. If 'Yes' to the above question, what is the name of the university you attended?

   ____

3. What was your major department in the Fall of 1967?

   ____

4. What was your program level in Fall '67? (CHECK ONE)

   a) Master's candidate ☐ (15-6)

   b) Doctoral candidate ☐ (15-7)

   c) 3rd or 4th year veterinary Medicine ☐ (15-9)

   d) Other (SPECIFY) ______________ ☐ (15-1)

5. What is your sex? (CHECK ONE)

   a) Male ☐ (16-1)

   b) Female ☐ (16-2)

6. What is your marital status? (CHECK ONE)

   a) Single ☐ (17-1)

   b) Married ☐ (17-2)

   c) Widowed, Divorced or Separated ☐ (17-3)

7. If married, does your spouse earn part of your family income? (CHECK ONE)

a) Yes	☐	(18-1)
b) No	☐	(18-2)

8. When did you first consider the possibility of attending MSU? (CHECK ONE)

a) 8th grade or earlier	☐	(19-1)
b) 9th - 10th grade	☐	(19-2)
c) 11th - 12th grade	☐	(19-3)
d) During the years between high school and undergraduate school	☐	(19-4)
e) During undergraduate school	☐	(19-5)
f) During the years I was not in school, between undergraduate and graduate school	☐	(19-6)
g) During graduate school	☐	(19-7)
h) During the time I was not in school after I had started graduate school	☐	(19-8)

9. Do any of your family members (parents, wife, brothers, sisters) attend, or have they attended MSU? (CHECK ONE)

a) Yes	☐	(20-1)
b) No	☐	(20-2)

IF YOU DID NOT ATTEND A COLLEGE/UNIVERSITY IN THE FALL OF 1967, SKIP TO QUESTION NO. 17.

10. Who, other than yourself, do you think had the most influence upon your decision to go to another school or postpone attending MSU in Fall '67?

a) No one else	☐	(21-1)
b) Parents	☐	(21-2)
c) Faculty at that university	☐	(21-3)
d) Teachers in high school	☐	(21-4)
e) High school counselor	☐	(21-5)
f) Other alumni of that university	☐	(21-6)
g) High school friends	☐	(21-7)
h) Others (SPECIFY)	☐	(21-8)

NOTE: STUDENTS WHO ATTENDED A DIFFERENT SCHOOL IN THE FALL OF 1967 SHOULD ANSWER THE FOLLOWING QUESTIONS WITH RESPECT TO THE SCHOOL THEY ATTENDED IN THE FALL OF 1967.

11. What type or types of financial resources are supporting your studies at the university you are attending. (CHECK AS MANY AS APPLY)

a) Financial aid[**]	☐	(22-1)
b) Campus job (full or part-time)	☐	(23-1)
c) Off-campus job (full or part-time)	☐	(24-1)
d) G I Bill	☐	(25-1)
e) Wife's earnings	☐	(26-1)
f) Personal savings	☐	(27-1)
g) Parental assistance	☐	(28-1)
h) Loan	☐	(29-1)
i) Other resources (SPECIFY)	☐	(30-1)

12. In the above list of resources which one contributes the major part of your income? (CIRCLE THE LETTER TO THE LEFT OF THE RESOURCE CHOSEN.) (31)

IF YOU ARE NOT RECEIVING FINANCIAL AID, PLEASE SKIP TO QUESTION 15.

13. If you receive financial aid, what type of financial aid is it? (CHECK ONE)

a) Graduate TeachingAssistantship	☐	(32-1)
b) Graduate Research Assistantship	☐	(32-2)
c) Fellowship	☐	(32-3)
d) Tuition scholarships only	☐	(32-4)
e) Other scholarship	☐	(32-5)
f) Other aid (SPECIFY)	☐	(32-6)

[**] Financial Aids in the present study include teaching assistantships, research assistantships, fellowships, scholarships, tuition scholarships and grants.

NOTE: Financial Aids do not include loans.

14. If you received either a fellowship, scholarship or tuition scholarship, which one of the following statements is true about the financial aid you receive? (CHECK ONE)

a) It is specified to a particular field of study and can be used at that university only ☐ (33-1)

b) It is general (unspecified as to field) and can be used at that university only ☐ (33-2)

c) It is specified to a particular field of study and would be valid at any university I chose to attend ☐ (33-3)

d) It is general (unspecified as to field) and would be valid at any university I chose to attend ☐ (33-4)

15. At the time you completed the formal application requesting financial aid from MSU, did you already have an informal understanding from a faculty member at MSU that financial aid would be available to you? (CHECK ONE)

a) Yes ☐ (34-1)

b) No ☐ (34-2)

c) Not sure ☐ (34-3)

d) Did not apply for financial aid ☐ (34-4)

16. Which one of the following statements is true of all financial aid you ever received? (CHECK ONE)

a) I have received financial aid continuously since the beginning of my present degree program (including Summer). (35-1)

b) I have received financial aid continuously since the beginning of my present degree program (except Summer). ☐ (35-2)

c) I have received financial aid continuously but it began after I started my present degree program (except possibly Summer terms). ☐ (35-3)

d) I have received financial aid intermittently in my present degree program. ☐ (35-4)

e) I did not receive any financial aid in my present degree program. ☐ (35-5)

17. Please indicate how attractive each of the following characteristics of MSU were when you made the decision to go to another school or postpone attending MSU in the Fall of '67. (CIRCLE ONE NUMBER IN EACH ROW BELOW)

	Very Unattractive	Unattractive	Neither	Attractive	Very Attractive	
__a) Curriculum of my major	1	2	3	4	5	(36)
__b) Faculty reputation in my field	1	2	3	4	5	(37)
__c) General reputation of the university	1	2	3	4	5	(38)
__d) Financial aid through the university	1	2	3	4	5	(39)
__e) Off-campus job opportunities for myself and wife	1	2	3	4	5	(40)
__f) Campus job opportunities for myself and wife	1	2	3	4	5	(41)
__g) Educational facilities (library, computer, etc.)	1	2	3	4	5	(42)
__h) Location of campus	1	2	3	4	5	(43)
__i) Appearance of the campus	1	2	3	4	5	(44)
__j) Employment opportunities after completion of degree	1	2	3	4	5	(45)
__k) Low costs (tuition and other expenses)	1	2	3	4	5	(46)
__l) Loan facilities	1	2	3	4	5	(47)

18. Please select the five factors from the list a through l in question 17 which you think are most influential in your decision to attend a university. Rank them in order of their influence by filling the numbers one (1) through five (5) in the spaces to the left in question 17.

NOTE: 1 = Most influential
2 = Least influential

IF YOU ATTENDED A UNIVERSITY IN THE FALL OF 1967, SKIP TO QUESTION NO. 21.

19. Please name some university (other than Michigan State University) you know well.

Name (without abbreviation) Location (city and state)

20. How did you first get to know about the university named in question 19?

a) I was a student there in the past. ☐ (66-1)

b) I knew someone who was a student there. ☐ (66-2)

c) I know about it in some other way. (SPECIFY) ☐ (66-3)

21. Compared to the university you attended in the Fall term '67, (or the university you named in question 19), how would you rate MSU on each item below. (CIRCLE ONE NUMBER IN EACH ROW.)

	MSU is much worse	MSU is worse	no opinion	MSU is better	MSU is much better	
a) Financial aid available	1	2	3	4	5	(7)
b) Library facilities	1	2	3	4	5	(8)
c) Computer facilities	1	2	3	4	5	(9)
d) Faculty guidance	1	2	3	4	5	(10)
e) Curriculum of my major	1	2	3	4	5	(11)
f) Laboratory and shop facilities	1	2	3	4	5	(12)
g) Costs (including tuition fees)	1	2	3	4	5	(13)
h) Friendliness of students	1	2	3	4	5	(14)
i) Intercollegiate athletics	1	2	3	4	5	(15)
j) Housing for married students	1	2	3	4	5	(16)
k) Dormitories	1	2	3	4	5	(17)
l) Academic reputation	1	2	3	4	5	(18)
m) Instruction	1	2	3	4	5	(19)
n) Loan facilities	1	2	3	4	5	(20)
o) Student-Faculty ratio (Graduate)	1	2	3	4	5	(21)
p) Student-Faculty ratio (Undergraduate)	1	2	3	4	5	(22)
q) Faculty attitude towards students	1	2	3	4	5	(23)

22. When you applied to MSU, to how many other universities did you apply simultaneously?

Number: _______ (24)

23. How many of these universities admitted you?

Number: _______ (25)

24. Did you apply for financial aid at MSU and/or other universities? (CHECK ONE)

a) At MSU ☐ (26-1)
b) At other universities ☐ (26-2)
c) At both MSU and other universities ☐ (26-3)
d) Did not apply for financial aid ☐ (26-4)

25. If you did ask for financial aid, what is the main reason you decided to ask for financial aid? (CHECK ONE)

a) I needed the money to continue my education. ☐ (27-1)
b) I desired the professional and educational benefits of work experience. ☐ (27-2)
c) I felt that my past record justified financial aid. ☐ (27-3)
d) Other reasons (SPECIFY) ________________________ ☐ (27-4)

26. Did you receive offers of financial aid from MSU and/or other universities? (CHECK ONE)

a) From MSU ☐ (28-1)
b) From other universities ☐ (28-2)
c) From both MSU and other universities ☐ (28-3)
d) Did not receive offers of financial aid ☐ (28-4)

27. If you checked "C" above, how does MSU's offer compare with the best of the other offers? (CHECK ONE)

a) Higher than MSU's offer ☐ (29-1)
b) Same as MSU's offer ☐ (29-2)
c) Lower than MSU's offer ☐ (29-3)
d) Not comparable to MSU's offer ☐ (29-4)

28. How many of the other universities offered you financial aid?

Number: _______ (30)

29. Which of the following reasons contributed to your decision to go to another school or postpone attending MSU in Fall, 1967? (CHECK AS MANY AS APPLY)

a) I received an offer of more financial aid from another university.	☐	(31-1)
b) I received a similar offer at another university and attended the other university since it was a preferable university.	☐	(32-1)
c) I received a lower offer of financial aid from another university but preferred it since it was a better university.	☐	(33-1)
d) I received an offer of Fellowship or Scholarship at another university which required no time committment.	☐	(34-1)
e) I heard from MSU too late about financial aid and by then, I had decided to go to another university or not attend school in Fall '68.	☐	(35-1)
f) My decision has nothing to do with MSU's offer of financial aid.	☐	(36-1)

30. Referring to the list of reasons in question 29, which one of these reasons made the most important contribution to your decision to go to another school or postpone attending MSU in Fall '67? (CIRCLE THE LETTER TO THE LEFT OF THE REASON ABOVE) (37)

31. If "a" in question 29, how much more financial aid per 10 months were you offered at another university than MSU offered you? (PLEASE SPECIFY AMOUNT)

$______________________________ (38)

32. What would have been the minimum amount of MSU's offer of financial aid for a 10 month period in order to have changed your decision about attending MSU in Fall of 1967. (PLEASE SPECIFY AMOUNT)

$______________________________ (39)

33. Did the ability to pay plan of MSU influence your decision to go to another school or postpone attending MSU in the Fall of 1967? (CHECK ONE)

a) Yes	☐	(40-1)
b) No	☐	(40-2)

34. Why did you decide to obtain the degree (B.A., M.S., Ph.D., etc.) you are now working on? (CHECK BOXES ON RIGHT)

a) Someone else thought I should go to graduate school.	☐	(41)
b) I am interested in pursuing advanced studies for scholarly reasons.	☐	(42)
c) The type of career I want requires this degree.	☐	(43)
d) I could not get the job I wanted, so I decided to stay in school.	☐	(44)
e) Other factors (PLEASE SPECIFY)	☐	(45)

____

35. Please select the one factor from the list in question 34 which you think was most influential in your decision. (CIRCLE THE LETTERS OF THE STATEMENTS IN QUESTION 34) (46)

36. What do you expect your annual starting salary will be when you complete the degree for which you are working? (CHECK ONE)

a) Under $5,000	☐	(47-1)
b) $5,000 to $6,999	☐	(47-2)
c) $7,000 to $8,999	☐	(47-3)
d) $9,000 to $10,999	☐	(47-4)
e) $11,000 to $12,999	☐	(47-5)
f) $13,000 to $14,999	☐	(47-6)
g) $15,000 to $16,999	☐	(47-7)
h) $17,000 or over	☐	(47-8)

37. What would your starting salary be without the degree you are now working for? (CHECK ONE)

a) Under $5,000 ☐ (48-1)
b) $5,000 to $6,999 ☐ (48-2)
c) $7,000 to $8,999 ☐ (48-3)
d) $9,000 to $10,999 ☐ (48-4)
e) $11,000 to $12,999 ☐ (48-5)
f) $13,000 to $14,999 ☐ (48-6)
g) $15,000 to $16,999 ☐ (48-7)
h) $17,000 and over ☐ (48-8)

38. Which one of the following statements describes your plans for further graduate study? (CHECK ONE)

a) I plan to attend graduate school at MSU in the future. ☐ (50-1)
b) I plan to attend graduate school elsewhere in the future. ☐ (50-2)
c) I am not certain about my graduate school plans. ☐ (50-3)
d) I do not intend to go further in graduate school. ☐ (50-4)

39. What is the main reason for your decision in the last question? (CHECK ONE)

a) Academic reasons ☐ (51-1)
b) Occupational reasons ☐ (51-2)
c) Financial reasons ☐ (51-3)
d) Personal reasons (other than financial) ☐ (51-4)
e) Other reasons (SPECIFY) ☐ (51-5)

____

40. How do you feel about your decision to go to another school or postpone attending MSU in the Fall of 1967? (CHECK ONE)

a)	I am extremely satisfied with my decision.	☐	(52-1)
b)	I am somewhat satisfied with my decision.	☐	(52-2)
c)	I am neither satisfied nor dissatisfied with my decision.	☐	(52-3)
d)	I am somewhat dissatisfied with my decision.	☐	(52-4)
e)	I am extremely dissatisfied with my decision.	☐	(52-5)

41. Please indicate how satisfactory each of the following factors was for you during your early experience with MSU. (CIRCLE ONE NUMBER IN EACH ROW)

	Very Unsatis-factory	Unsatis-factory	No Opinion	Satis-factory	Very Satis-factory	
a) Promptness of information before I applied	1	2	3	4	5	(53)
b) Clarity of information before I applied	1	2	3	4	5	(54)
c) Completeness of information before I applied	1	2	3	4	5	(55)
d) Accuracy of information before I applied	1	2	3	4	5	(56)
e) Promptness of information about my admission	1	2	3	4	5	(57)
f) Promptness of information about my financial aid	1	2	3	4	5	(58)
g) Individual attention to information about admission and financial aid	1	2	3	4	5	(59)

41. What in your opinion, should MSU do to attract quality graduate students?

____

____

____

____ (60)

42. What was the size of your high school graduating class? (CHECK ONE)

a) Less than 100	☐	(61-1)
b) 100 to 199	☐	(61-2)
c) 200 to 299	☐	(61-3)
d) 300 to 499	☐	(61-4)
e) 500 or more	☐	(61-5)

43. What size town or city did you live in while attending high school? (If you have lived in more than one town or city, check the one size of town where you spent most of your time in high school.)

a) Under 2,000	☐	(62-1)
b) 2,000 to 4,999	☐	(62-2)
c) 5,000 to 9,999	☐	(62-3)
d) 10,000 to 24,999	☐	(62-4)
e) 25,000 to 74,999	☐	(62-5)
f) 75,000 to 149,999	☐	(62-6)
g) 150,000 and over	☐	(62-7)

44. While you were an undergraduate, what was the size of the total student body, (both graduate and undergraduate), at the campus you attended. (If you have attended more than one school as an undergraduate, check the one size of campus where you earned the maximum number of credits.)

a) Under 5,000	☐	(63-1)
b) 5,000 to 9,999	☐	(63-2)
c) 10,000 to 19,999	☐	(63-3)
d) 20,000 to 34,999	☐	(63-4)
e) 35,000 and above	☐	(63-5)

45. Please list the name and location of the last one or two colleges or universities attended before entering your present degree program. (Include MSU if you attended here before entering your present program). (64)

Name of Institution	Location	Dates of attendance	Degree/credits earned
a)			
b)			

46. What is (was) your GPA (Grade-Point-Average)? (CHECK ONE IN EACH COLUMN)

In your present degree program (column 1)		At the time of entering your present degree program (column 2)
☐	Equal to or higher than 3.5	☐
☐	Equal to or higher than 3.0 but less than 3.5	☐
☐	Equal to or higher than 2.5 but less than 3.0	☐
☐	Equal to or higher than 2.0 but less than 2.5	☐
☐	Less than 2.0	☐

47. What is your father's educational level? (CHECK THE HIGHEST DEGREE/ DIPLOMA EARNED)

a) He did not complete high school.	☐	(67-1)
b) He earned a high school diploma.	☐	(67-2)
c) He earned a bachelor's degree.	☐	(67-3)
d) He earned a master's degree.	☐	(67-4)
e) He earned a doctoral degree. (Ph. D., Ed. D., M. D., D. D. S., D. V. M., etc.).	☐	(67-5)
f) Other (SPECIFY)	☐	(67-6)

____

48. If your father earned a college degree or diploma what was his major field of study? (PLEASE WRITE IN SPACE BELOW)

49. Which one of the following statements is true of your father when you were a Senior in high school? (CHECK ONE)

a) He was self employed.	☐	(70-1)
b) He was employed by others.	☐	(70-2)
c) He was not employed.	☐	(70-3)
d) He was retired.	☐	(70-4)
e) Other (SPECIFY)	☐	(70-5)

50. What is your mother's education? (CHECK THE HIGHEST DEGREE OR DIPLOMA EARNED)

a) She did not complete high school.	☐	(71-1)
b) She earned a high school diploma.	☐	(71-2)
c) She earned a bachelor's degree.	☐	(71-3)
d) She earned a master's degree.	☐	(71-4)
e) She earned a doctoral degree (Ph. D., Ed. D., M. D., D. V. M., etc.).	☐	(71-5)
d) Other (SPECIFY)	☐	(71-6)

51. If your mother earned a college degree or diploma, what was her major field of study? (PLEASE WRITE IN THE SPACE BELOW)

52. Which one of the following statements is true of your mother when you were a Senior in high school? (CHECK ONE)

a) She was a part-time employee.	☐	(74-1)
b) She was a full-time employee.	☐	(74-2)
c) She was self employed.	☐	(74-3)
d) She was not employed.	☐	(74-4)
e) Other (SPECIFY)	☐	(74-5)

53. What is the gross annual income of your parents at the present time? (INCLUDE ALL SOURCES OF INCOME AND CHECK ONE)

a) Under $5,000	☐	(75-1)
b) $5,000 to $7,499	☐	(75-2)
c) $7,500 to $11,999	☐	(75-3)
d) $12,000 to $16,499	☐	(75-4)
e) $16,500 to $20,999	☐	(75-5)
f) $21,000 to $25,499	☐	(75-6)
g) $25,500 and over	☐	(75-7)

54. Regardless of your sex, which of the following statements was most true for you before the mid-February (1968) decision to discontinue student deferments for most graduate students? (CHECK ONE)

a) The draft had not influenced my plans for graduate school.	☐	(76-1)
b) The draft had influenced me to continue or begin graduate school.	☐	(76-2)
c) The draft had influenced me to postpone my graduate studies.	☐	(76-3)
d) The draft had influenced me to withdraw from graduate school.	☐	(76-4)

55. Regardless of your sex, which of the following statements is most true for you now that the decision has been made to discontinue student deferments for most graduate students? (CHECK ONE)

a) The new decision has not influenced my plans for graduate school.	☐	(77-1)
b) The new decision has influenced me to continue or begin graduate school.	☐	(77-2)
c) The new decision has influenced me to postpone my graduate studies.	☐	(77-3)
d) The new decision has influenced me to withdraw from graduate school.	☐	(77-4)

FEMALES NEED NOT CONTINUE FURTHER. THANK YOU VERY MUCH FOR YOUR COOPERATION.

56. What is your present draft classification? (78)

a) I-A ☐
b) I-A-O ☐
c) I-O ☐
d) I-S ☐
e) I-Y ☐
f) I-D ☐
g) I-W ☐
h) I-C ☐
i) II-A ☐
j) II-S ☐
k) III-A ☐
l) IV-A ☐
m) IV-B ☐
n) IV-C ☐
o) IV-D ☐
p) IV-F ☐
q) V-A ☐

Thank you very much for your cooperation. (80-2)

MICHIGAN STATE UNIVERSITY EAST LANSING · MICHIGAN 48823

COLLEGE OF ENGINEERING · ENGINEERING BUILDING

May 1, 1968

To: (Advanced Students at MSU)

As part of a research program sponsored by the National Science Foundation, Office of Education and Manpower Studies we are conducting an in depth study of the decisions made by graduates in selecting their graduate schools This information will be used in an effort to determine the influence of various financial aid programs on graduate enrollments and in an effort to model, mathematically, certain aspects of the university business operation.

We are drawing a random sample of about 10% of our graduate and senior student population. The fact you have this questionnaire in hand implies that you are part of this random sample.

Your answers will be held in strict confidence by our staff members and the analysis will in no way associate your name with your answers. We must ask for student numbers in order to know which persons in the random sample have not returned their answers to us.

For your convenience, we are enclosing a postage paid, self addressed envelope. However, we prefer the questionnaire be returned by Campus mail. The pilot study indicated that it takes about 20 minutes to fill out the questionnaire.

We thank you in advance for your cooperation. Your cooperation will help us answer questions that are of direct concern to the institutions of higher education.

Sincerely,

H E Koenig

H. E. Koenig, Director
Systems Science Program

HEK:nab
enclosure

SURVEY OF ADVANCED STUDENTS AT MSU - SPRING 1968

Systems Science Group
Division of Engineering Research
Michigan State University

1. What is your major (department) ? ______________________________

2. What are your minors (departments), if any?

a) ______________________________
b) ______________________________
c) ______________________________

3. What is your program level? (PLEASE CHECK ONE)

a) Senior ☐ (15-4)
b) Master's candidate ☐ (15-6)
c) Doctoral candidate ☐ (15-7)
d) 3rd or 4th year Veterinary Medicine ☐ (15-9)
e) Other (SPECIFY) ______________________________ ☐ (15-1)

4. What is your sex? (CHECK ONE)

a) Male ☐ (16-1)
b) Female ☐ (16-2)

5. What is your marital status? (CHECK ONE)

a) Single ☐ (17-1)
b) Married ☐ (17-2)
c) Widowed, Divorced or Separated ☐ (17-3)

6. If married, does your spouse earn part of your family income? (CHECK ONE)

a) Yes ☐ (18-1)
b) No ☐ (18-2)

7. When did you first consider the possibility of attending MSU? (CHECK ONE)

a) 8th grade or earlier	☐	(19-1)
b) 9th - 10th grade	☐	(19-2)
c) 11th - 12th grade	☐	(19-3)
d) During the years between high school and undergraduate	☐	(19-4)
e) During undergraduate years	☐	(19-5)
f) During the years I was not in school between undergraduate and graduate	☐	(19-6)
g) During graduate years	☐	(19-7)
h) During the time I was not in school after graduate studies	☐	(19-8)

8. Do any of your family members (parents, wife, brothers, sisters) attend, or have they attended, MSU? (CHECK ONE)

a) Yes	☐	(20-1)
b) No	☐	(20-2)

9. Who other than yourself do you think had the most influence upon your decision to come to MSU? (CHECK ONE)

a) No one else	☐	(21-1)
b) Parents	☐	(21-2)
c) Faculty at MSU	☐	(21-3)
d) Teachers in high school	☐	(21-4)
e) High school counselor	☐	(21-5)
f) Other alumni of MSU	☐	(21-6)
g) High school friends	☐	(21-7)
h) Others (SPECIFY)	☐	(21-8)

____

10. What type or types of financial resources are supporting your studies at MSU? (CHECK AS MANY AS APPLY)

a) Financial aid**	☐	(22-1)
b) Campus job (full or part-time)	☐	(23-1)
c) Off-campus job (full or part time)	☐	(24-1)
d) G. I. Bill	☐	(25-1)
e) Wife's earnings	☐	(26-1)
f) Personal savings	☐	(27-1)
g) Parental assistance	☐	(28-1)
h) Loan	☐	(29-1)
i) Other resources (SPECIFY)	☐	(30-1)

____

11. In the above list of resources which one contributes the major part of your income? (CIRCLE THE LETTER TO THE LEFT OF THE RESOURCE CHOSEN) (31)

IF YOU ARE NOT RECEIVING FINANCIAL AID, PLEASE SKIP TO QUESTION 14.

12. If you receive financial aid, what type of financial aid is it? (CHECK ONE)

a) Graduate Teaching Assistantship	☐	(32-1)
b) Graduate Research Assistantship	☐	(32-2)
c) Fellowship	☐	(32-3)
d) Tuition scholarships only	☐	(32-4)
e) Other scholarship	☐	(32-5)
f) Other aid (SPECIFY)	☐	(32-6)

____

**Financial Aids in the present study include teaching assistantships, research assistantships, fellowships, scholarships, tuition scholarships and grants.

NOTE: Financial Aids do not include loans.

13. If you receive either a fellowship, scholarship or tuition scholarship, which one of the following statements is true about the financial aid you receive? (CHECK ONE)

a) It is specified to a particular field of study and can be used at MSU only. ☐ (33-1)

b) It is general (unspecified as to field) and can be used at MSU only. ☐ (33-2)

c) It is specified to a particular field of study and would be valid at any university I chose to attend. ☐ (33-3)

d) It is general (unspecified as to field) and would be valid at any university I chose to attend. ☐ (33-4)

14. At the time you completed the formal application requesting financial aid, did you already have an informal understanding from a faculty member at MSU that financial aid would be available to you? (CHECK ONE)

a) Yes ☐ (34-1)

b) No ☐ (34-2)

c) Not sure ☐ (34-3)

d) Did not apply for financial aid ☐ (34-4)

15. Which one of the following statements is true of all financial aid you ever received? (CHECK ONE)

a) I received financial aid continuously since the beginning of my present degree program (including Summer). ☐ (35-1)

b) I received financial aid continuously since the beginning of my present degree program (except Summer). ☐ (35-2)

c) I received financial aid continuously, but it began after I started my present degree program (except possibly Summer terms). ☐ (35-3)

d) I received financial aid intermittently in my present degree program. ☐ (35-4)

e) I did not receive any financial aid in my present degree program. ☐ (35-5)

16. Please indicate how attractive each of the following characteristics of MSU was when you made the decision to come to MSU. (CIRCLE ONE NUMBER IN EACH ROW BELOW)

	Very Unattractive	Unattractive	Neither	Attractive	Very Attractive	
__a) Curriculum of my major	1	2	3	4	5	(36)
__b) Faculty reputation in my field	1	2	3	4	5	(37)
__c) General reputation of the university	1	2	3	4	5	(38)
__d) Financial aid through the university	1	2	3	4	5	(39)
__e) Off-campus job opportunities for myself and wife	1	2	3	4	5	(40)
__f) Campus job opportunities for myself and wife	1	2	3	4	5	(41)
__g) Educational facilities (library, computer, etc.)	1	2	3	4	5	(42)
__h) Location of campus	1	2	3	4	5	(43)
__i) Appearance of the campus	1	2	3	4	5	(44)
__j) Employment opportunities after completion of degree	1	2	3	4	5	(45)
__k) Low costs (tuition and other expenses)	1	2	3	4	5	(46)
__l) Loan facilities	1	2	3	4	5	(47)

17. Please select the five factors from the list (a through l) in question 16 which you think are most influential in your decision to attend a university. Rank them in order of their influence by filling the numbers one (1) through five (5) in the spaces to the left in question 16.

NOTE: 1 = Most influential

5 = Least influential

18. Please name some university (other than Michigan State University) you know well.

____

Name (without abbreviation) Location (city and state)

19. How did you first get to know about the university named in question 18?

a) I was a student there in the past. ☐ (66-1)

b) I knew someone who was a student there. ☐ (66-2)

c) I know about it in some other way. (SPECIFY) ☐ (66-3)

____

20. Compared to the university named in question 18, how would you rate MSU on each item below? (CIRCLE ONE NUMBER IN EACH ROW)

	MSU is much worse	MSU is worse	no opinion	MSU is better	MSU is much better	
a) Financial aid available	1	2	3	4	5	(7)
b) Library facilities	1	2	3	4	5	(8)
c) Computer facilities	1	2	3	4	5	(9)
d) Faculty guidance	1	2	3	4	5	(10)
e) Curriculum	1	2	3	4	5	(11)
f) Workshops	1	2	3	4	5	(12)
g) Costs including tuition fees	1	2	3	4	5	(13)
h) Friendliness of students	1	2	3	4	5	(14)
i) Intercollegiate athletics	1	2	3	4	5	(15)
j) Housing for married students	1	2	3	4	5	(16)
k) Dormitories	1	2	3	4	5	(17)
l) Academic reputation	1	2	3	4	5	(18)
m) Instruction	1	2	3	4	5	(19)
n) Loan facilities	1	2	3	4	5	(20)
o) Student-faculty ratio (graduate)	1	2	3	4	5	(21)
p) Student-faculty ratio (undergraduate)	1	2	3	4	5	(22)

21. When you applied to MSU, to how many other universities did you apply simultaneously?

Number: ____________ (24)

22. How many of these universities admitted you?

Number: ____________

23. Did you apply for financial aid at MSU and/or other universities? (CHECK ONE)

a) At MSU ☐ (26-1)
b) At other universities ☐ (26-2)
c) At both MSU and other universities ☐ (26-3)
d) Did not apply for financial aid ☐ (26-4)

24. If you did ask for financial aid, what is the main reason you decided to ask for financial aid? (CHECK ONE)

a) I needed the money to continue my education. ☐ (27-1)
b) I desired the professional and educational benefits of work experience. ☐ (27-2)
c) I felt that my past record justified financial aid. ☐ (27-3)
d) Other reasons (SPECIFY) ☐ (27-4)

____

25. Did you receive offers of financial aid from MSU and/or other universities? (CHECK ONE)

a) From MSU ☐ (28-1)
b) From other universities ☐ (28-2)
c) From both MSU and other universities ☐ (28-3)
d) Did not receive offers of financial aid ☐ (28-4)

26. If you checked "C" above, how does MSU's offer compare with the best of the other offers? (CHECK ONE)

a) Higher than MSU's offer ☐ (29-1)
b) Same as MSU's offer ☐ (29-2)
c) Lower than MSU's offer ☐ (29-3)
d) Not comparable to MSU's offer ☐ (29-4)

27. How many of the other universities offered you financial aid?

Number: __________ (30)

28. If MSU had not given you financial aid, what would have been your most likely action? (CHECK ONE)

a) I would have gone to another school. ☐ (31-1)

b) I would have looked for employment (campus or off-campus) and attended MSU. ☐ (31-2)

c) I would have used other forms of support (loans, etc., parents-wife support) and attended MSU. ☐ (31-3)

d) I would have accepted employment and postponed attending school. ☐ (31-4)

e) Difficult to say. ☐ (31-5)

29. In the absence of financial aid from MSU what was the probability you would have attended MSU? (CHECK ONE)

a) 0% chance ☐ (32-1)

b) 1% to 20% chance ☐ (32-2)

c) 21% to 40% chance ☐ (32-3)

d) 41% to 60% chance ☐ (32-4)

e) 61% to 80% chance ☐ (32-5)

f) 81% to 99% chance ☐ (32-6)

g) 100% chance ☐ (32-7)

30. Why did you decide to obtain the degree (B.A., M.S., Ph.D., etc.) you are now working on? (CHECK BOXES ON RIGHT)

a) Someone else thought I should go to graduate school. ☐ (33)

b) I am interested in pursuing advanced studies for scholarly reasons. ☐ (34)

c) The type of career I want requires this degree. ☐ (35)

d) I could not get the job I wanted, so I decided to stay in school. ☐ (36)

e) Other factors (PLEASE SPECIFY) ☐ (37)

____

31. Please select the one factor from the list in question 30 which you think was most influential in your decision. (CIRCLE THE LETTER TO THE LEFT OF THE STATEMENTS IN QUESTION 30) (38)

32. Which one of the following statements is true about your current payment of tuition fees? (CHECK ONE)

a) I pay in-state tuition fees because I am a resident of Michigan. ☐ (39-1)
b) I pay in-state tuition fees because of the financial aid I receive from MSU. ☐ (39-2)
c) I pay in-state tuition fees because of other special considerations. ☐ (39-3)
d) I pay out-of-state tuition fees. ☐ (39-4)
e) I have a tuition scholarship which completely pays my tuition fees. ☐ (39-5)

33. Which one of the following statements is true about your opinion of MSU's ability to pay (tuition) plan?

a) I am in favor of the ability to pay plan. ☐ (40-1)
b) I am against the ability to pay plan. ☐ (40-2)
c) I am indifferent (neutral) to the ability to pay plan. ☐ (40-3)

34. What do you expect your annual starting salary will be when you complete the degree for which you are working? (CHECK ONE)

a) Under $5,000 ☐ (47-1)
b) $5,000 to $6,999 ☐ (47-2)
c) $7,000 to $8,999 ☐ (47-3)
d) $9,000 to $10,999 ☐ (47-4)
e) $11,000 to $12,999 ☐ (47-5)
f) $13,000 to $14,999 ☐ (47-6)
g) $15,000 to $16,999 ☐ (47-7)
h) $17,000 or over ☐ (47-8)

35. What would your starting salary be without the degree you are now working for? (CHECK ONE)

a) Under $5,000 ☐ (48-1)
b) $5,000 to $6,999 ☐ (48-2)
c) $7,000 to $8,999 ☐ (48-3)
d) $9,000 to $10,999 ☐ (48-4)
e) $11,000 to $12,999 ☐ (48-5)
f) $13,000 to $14,999 ☐ (48-6)
g) $15,000 to $16,999 ☐ (48-7)
h) $17,000 and over ☐ (48-8)

36. If you are currently an undergraduate student, which one of the following statements describes your plans for graduate study? (CHECK ONE)

a) I plan to attend graduate school at MSU in the future. ☐ (49-1)
b) I plan to attend graduate school elsewhere in the future. ☐ (49-2)
c) I am not certain about my graduate school plans. ☐ (49-3)
d) I do not intend to go to graduate school. ☐ (49-4)

37. If you are currently beyond a bachelor's degree, which one of the following statements describes your plans for further graduate study? (CHECK ONE)

a) I plan to attend graduate school at MSU in the future. ☐ (50-1)
b) I plan to attend graduate school elsewhere in the future ☐ (50-2)
c) I am not certain about my graduate school plans. ☐ (50-3)
d) I do not intend to go further in graduate school. ☐ (50-4)

38. What is the main reason for your decision in question 36 or 37. (CHECK ONE)

a) Academic reasons ☐ (51-1)
b) Occupational reasons ☐ (51-2)
c) Financial reasons ☐ (51-3)
d) Personal reasons (other than financial) ☐ (51-4)
e) Other reasons (SPECIFY) ☐ (51-5)

39. How do you feel about your decision to come to MSU? (CHECK ONE)

a)	I am extremely satisfied with my decision.	☐	(52-1)
b)	I am somewhat satisfied with my decision.	☐	(52-2)
c)	I am neither satisfied nor dissatisfied with my decision.	☐	(52-3)
d)	I am somewhat dissatisfied with my decision.	☐	(52-4)
e)	I am extremely dissatisfied with my decision.	☐	(52-5)

40. Please indicate how satisfactory each of the following factors was for you during your early experience with MSU. (CIRCLE ONE NUMBER IN EACH ROW)

	Very Unsatisfactory	Unsatisfactory	No Opinion	Satisfactory	Very Satisfactory	
a) Promptness of information before I applied	1	2	3	4	5	(53)
b) Clarity of information before I applied	1	2	3	4	5	(54)
c) Completeness of information before I applied	1	2	3	4	5	(55)
d) Accuracy of information before I applied	1	2	3	4	5	(56)
e) Promptness of information about my admission	1	2	3	4	5	(57)
f) Promptness of information about my financial aid	1	2	3	4	5	(58)
g) Individual attention to information about admission and financial aid	1	2	3	4	5	(59)

41. What in your opinion should MSU do to attract quality graduate students?

____

____

____

____ (60)

42. What is your student number? ______________

43. What was the size of your high school graduating class? (CHECK ONE)

a) Less than 100	☐	(61-1)
b) 100 to 199	☐	(61-2)
c) 200 to 299	☐	(61-3)
d) 300 to 499	☐	(61-4)
e) 500 or more	☐	(61-5)

44. What size town or city did you live in while attending high school? (If you have lived in more than one town or city, check the one size of town where you spent most of your time in high school.)

a) Under 2,000	☐	(62-1)
b) 2,000 to 4,999	☐	(62-2)
c) 5,000 to 9,999	☐	(62-3)
d) 10,000 to 24,999	☐	(62-4)
e) 25,000 to 74,999	☐	(62-5)
f) 75,000 to 149,999	☐	(62-6)
g) 150,000 and over	☐	(62-7)

45. While you were an undergraduate, what was the size of the total student body (both graduate and undergraduate) at the campus you attended. (If you have attended more than one school as an undergraduate, check the one size of campus where you earned the maximum number of credits.)

a) Under 5,000	☐	(63-1)
b) 5,000 to 9,999	☐	(63-2)
c) 10,000 to 19,999	☐	(63-3)
d) 20,000 to 34,999	☐	(63-4)
e) 35,000 and above	☐	(63-5)

46. Please list the name and location of the last one or two colleges or universities attended before entering your present degree program. (Include MSU, if you attended here before entering your present program.)

Name of Institution	Location	Dates of attendance	Degree/credits earned
a)			
b)			

47. What is (was) your GPA? (CHECK ONE IN EACH COLUMN)

In your present degree program (column 1)		At the time of entering your present degree program (column 2)
☐	Equal to or higher than 3.5	☐
☐	Equal to or higher than 3.0 but less than 3.5	☐
☐	Equal to or higher than 2.5 but less than 3.0	☐
☐	Equal to or higher than 2.0 but less than 2.5	☐
☐	Less than 2.0	☐

48. What is your father's education? (CHECK THE HIGHEST DEGREE/ DIPLOMA EARNED)

a) He did not complete high school.	☐	(67-1)
b) He earned a high school diploma.	☐	(67-2)
c) He earned a bachelor's degree.	☐	(67-3)
d) He earned a master's degree.	☐	(67-4)
e) He earned a doctoral degree (Ph.D., Ed.D., M.D., D.D.S., D.V.M., etc.).	☐	(67-5)

f) Other (SPECIFY) ____________________

49. If your father earned a college degree or diploma what was his major field of study? (PLEASE WRITE IN SPACE BELOW)

50. Which one of the following statements is true of your father when you were a Senior in high school? (CHECK ONE)

a) He was self employed. ☐ (70-1)
b) He was employed by others. ☐ (70-2)
c) He was unemployed. ☐ (70-3)
d) He was retired. ☐ (70-4)
e) Other (SPECIFY) ☐ (70-5)

51. What is your mother's education? (CHECK THE HIGHEST DEGREE/ DIPLOMA EARNED)

a) She did not complete high school. ☐ (71-1)
b) She earned a high school diploma. ☐ (71-2)
c) She earned a bachelor's degree. ☐ (71-3)
d) She earned a master's degree. ☐ (71-4)
e) She earned a doctoral degree (Ph. D., Ed. D., M. D., D. V. M. etc.). ☐ (71-5)
f) Other (SPECIFY) ☐ (71-6)

52. If your mother earned a college degree or diploma, what was her major field of study? (PLEASE WRITE IN THE SPACE BELOW)

53. Which one of the following statements is true of your mother when you were a Senior in high school? (CHECK ONE)

a) She was a part-time employee. ☐ (74-1)
b) She was a full-time employee. ☐ (74-2)
c) She was self employed. ☐ (74-3)
d) She was not employed. ☐ (74-4)
e) Other (SPECIFY) ☐ (74-5)

54. What is the gross annual income of your parents at the present time? (INCLUDE ALL SOURCES OF INCOME AND CHECK ONE)

a) Under $5,000	☐	(75-1)
b) $5,000 to $7,499	☐	(75-2)
c) $7,500 to $11,999	☐	(75-3)
d) $12,000 to $16,499	☐	(75-4)
e) $16,500 to $20,999	☐	(75-5)
f) $21,000 to $25,499	☐	(75-6)
g) $25,500 and over	☐	(75-7)

55. Regardless of your sex, which of the following statements was most true for you before the mid-February (1968) decision to discontinue student deferments for most graduate students? (CHECK ONE)

a) The draft had not influenced my plans for graduate school.	☐	(76-1)
b) The draft had influenced me to continue or begin graduate school.	☐	(76-2)
c) The draft had influenced me to postpone my graduate studies.	☐	(76-3)
d) The draft had influenced me to withdraw from graduate school.	☐	(76-4)

56. Regardless of your sex, which of the following statements is most true for you now that the decision has been made to discontinue students deferments for most graduate students? (CHECK ONE)

a) The new decision has not influenced my plans for graduate school.	☐	(77-1)
b) The new decision has influenced me to continue or begin graduate school.	☐	(77-2)
c) The new decision has influenced me to postpone my graduate studies.	☐	(77-3)
d) The new decision has influenced me to withdraw from graduate school.	☐	(77-4)

FEMALES NEED NOT CONTINUE FURTHER. THANK YOU VERY MUCH FOR YOUR COOPERATION.

57. What is your present draft classification? (78)

a) I-A ☐
b) I-A-O ☐
c) I-O ☐
d) I-S ☐
e) I-Y ☐
f) I-D ☐
g) I-W ☐
h) I-C ☐
i) II-A ☐
j) II-S ☐
k) III-A ☐
l) IV-A ☐
m) IV-B ☐
n) IV-C ☐
o) IV-D ☐
p) IV-F ☐
q) V-A ☐

Thank you very much for your cooperation. (80-2)

4:2 A Proposed Faculty Record System

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4:2 A Proposed Faculty Central Record System

A plan is proposed and outlined to provide a centralized, coordinated, and mechanized Faculty Record System that will supply day-to-day operational data and at the same time serve as a portion of the university's data base providing complete, accurate, and comprehensive information to those university offices charged with various forms of faculty accounting and reporting.

The proposed system would eliminate the duplication of faculty data collection activity that now exists and provide to all concerned more extensive and detailed information about a most important resource of a university--the faculty.

The concept of a Central Faculty Record System is one of a centralized, magnetically-stored, coded, and segmented record of fixed length in machine-addressable format. The record itself consists of a fixed-length record, properly coded and segmented to permit editing and ease of sorting. This record or collection of subrecords, either sequential on magnetic tape or random access on a disk file, comprise the faculty data base.

Central offices would have the responsibility for the collection of data and for creating, maintaining, and deleting records. Report generation would be handled by the same offices for reasons of efficiency and security. Obviously, certain portions of the file would not be available to all who may request such data. In the event of an on-line random access remote terminal type of installation, a key-word system (or other alternatives to be mentioned later) could be employed to prevent unauthorized personnel from obtaining certain information.

The System

The faculty data acquisition and processing system presently under consideration is outlined below and pictorially represented in the tables and figures.

Conceptually, the information about each faculty member is a long, fixed-length magnetic record; but in practice, the record will be segmented into four smaller records on the basis of the type of data and frequency of use. This results in a record that is physically divided into four units which are, in this case, three magnetic tapes and one disk file. These four storage devices comprise the Central Faculty Record and are shown within the dotted lines of the flow chart Figure 4:2. I. The contents of each record are described below.

1. Current Activities Record

This record, as the name indicates, pertains to current activities of each faculty member. Information contained will include:

- a. Teaching load - The number of credits taught, students encountered, students advised, and student credit hours generated.
- b. Research in progress - Sponsored and non-sponsored.
- c. Time distribution - Percents of general fund time distributed among the functions of instruction, research, public services and administration.

2. Biographical Record

The biographical record will contain standard biographical data, i. e., date of birth, education, etc., and, in addition, will contain faculty resource data. Faculty resources include teaching competencies, research competencies and interests, language skills, and experience in foreign countries.

3. Publication Record

This record will contain a chronological listing of an individual's publications, coded as to type of publication and subject area. In addition, completed research projects will be contained within the record with codes to indicate degree of success.

We will maintain a file of grants requested and denied in order that the university may analyze the success of these requests as well as credit faculty members with the effort required to prepare a proposal.

4. Salary Budget, Payroll, and Faculty Benefits

Whereas the other three files are relatively straightforward and can tolerate a certain degree of lag in up-dating, this file must be accurate and current,for it will serve as the source tape for the issuance of pay checks under the control of the payroll program. A great deal of care must be exercised in the design of this file and the associated maintenance program. This file, when completed, will serve as a valuable data source for future planning and current gross data. Head count, average salary, and encumbered salary dollars will be available with breakdown by rank, tenure status, sex, and department.

These four records will provide a vast faculty data base with both depth and breadth to provide timely data for practically all the reporting required by the University, and they will also provide the information needed for planning and model building.

The Acquisition System

Under the planned acquisition system, a central office must be created with responsibility for the collection of the biographical and publication data. The budget-payroll record can be handled by modifying the existing systems. The current activities record will be created each term by modifying the existing data collection procedure in the Office of Institutional Research.

The individual record will be initiated by the processing of an appointment form and the associated biographical form. After the appointment is made, a request for publication data is sent to the new faculty member. With these forms as the source documents, the biographical, publication, and budget-payroll records are created and copies made for distribution to deans, department chairmen, and Information Services. Change of status, reappointment, and similar forms will serve to update the budget-payroll record. Biographical and publication files will be updated by sending completed copies of the forms to the individual faculty member instructing them to make the necessary corrections and additions. This will be done once a year, in the spring, and will be referred to as the Annual Faculty Questionnaire.

The System in Detail

1. Current Activities Record (CAR)

This record is an extension of the present Faculty Course Listing produced each term by the Office of Institutional Research.

It is proposed that this record be stored on magnetic tape in sequential order by social security number. The record size is approximately 2,000 characters which allows a maximum number of 13,930 records per reel of tape.

A. Record Design

The record itself consists of six sections that will facilitate the creation, maintenance and reporting from the record. The six sections are: (1) appointment data and time distribution, (2) direct instruction, (3) department sponsored research, (4) public and professional service, (5) administrative and committee service, and (6) contract research. The contents of the record are shown on the CAR form, page 239, Figure 4:2. II.

This tape record will serve as the input for the Faculty Course Listing and the Teaching Load and Time Distribution reports now produced by the Office of Institutional Research. In addition, this record could provide a more detailed look at faculty effort and appointment data. It is also possible that with careful design of some additional areas of the record much of the basic card work and card storage that occurs in the Office of Institutional Research can be eliminated.

B. Creation and Maintenance of Records

The CAR would be created each term by modifying existing data collection procedures in the Office of Institutional Research. A new file would be created each term and reports run from the completed tape. Old tapes would be retained for a period of time to provide a data base for studies requiring historical records.

C. Reporting

Reports similar to those now prepared by the Office of Institutional Research will be continued, with certain refinements, and other reports reflecting the improved data base will be generated to fill information gaps in the faculty activities area.

2. Biographical Record

The biographical record is the longest of the four records, being approximately 4,000 characters in length. It was originally hoped that all biographical data could be stored on magnetic tape, but the total length of the record would be too large for ease of machine processing.

The proposed system is to store 1,100 characters of condensed biographical data as a machine record. This record would contain that data required to answer the most frequently asked questions and to provide basic information about home address, office location, and other directory type information. The form is exhibited on page 240, Figure 4:2. III. Additional biographical information will be filed in the central office folders on three supplementary sheets. This data would not be stored on magnetic tape. The three forms are exhibited on pages 241, 242, and 243.

A. Record Design

The complete biographical file is stored on two media. Approximately 3,000 characters of information are stored in folders on the Education, Personal, and Employment forms designed to complement the biographical information stored on magnetic tape. These three forms and the tape record provide a complete biographical record for each individual.

The following information will be coded and stored on the condensed biographical tape record:

1. Name
2. Department
3. Social Security Number
4. Date of Birth
5. Sex
6. Marital Status
7. Name of Spouse
8. Local Address
9. Home Telephone
10. Citizenship Status
11. Foreign Language Ability
12. Military Status
13. Highest Earned Degree
14. Campus Address and Telephone
15. Original Appointment Data
16. Present Appointment Data
17. Tenure Status
18. Primary and Secondary Professional Fields

All of the above information is machine coded and stored providing the ability to list, tabulate, or cross tabulate any of these data or any combination of these data.

The three supplementary biographical forms contain the following information areas:

Education Form

1. Undergraduate Education
2. Graduate and Professional Education
3. Post-Doctoral Education
4. Fellowships
5. Honors Awards or Honorary Degrees
6. Professional Registrations, Licenses, Certifications

7. Memberships and Positions in Honorary, Learned or Professional Organizations

Personal Form

1. Dependents, Next of Kin
2. Parent Data
3. Business Data (if part time faculty)
4. Biographical Listings
5. Citizenship Data

Employment Form

1. Previous Professional Employment
2. M.S.U. Employment History
3. Sabbatical or Leave of Absence from M.S.U.
4. Foreign Travel and Residence

This information would not be stored on magnetic tape but would be stored in individual folders.

B. Creation and Maintenance of Records

The forms associated with this record would be filled out prior to appointment and provide the information required for departmental interview and appointment approval. This could eliminate a portion of the appointment form and allow revision of the form to provide more detail pertaining to the budgetary and payroll information.

Maintenance is accomplished periodically by sending copies of the records to each employee concerned and requesting that any additions and/or corrections be made and the form returned to update the tape record and the folder.

C. Reporting

Reports can be generated concerning any of the above-mentioned areas from the tape record, and individual files will be maintained to provide additional information about other data contained on the three supplementary forms. Reporting can be done on a routine or demand basis. Routine reports such as the local and home addresses needed for the Faculty-Staff Directory can be generated directly from the magnetic tape. Similarly, demand reports such as data needed for questionnaires can be retrieved from the tape record.

3. Publications Record

The publication record is a system to store and code up to 99 different areas of faculty scholarly activities. Presently some of this information is contained in various individual faculty folders on campus. However, the present system emphasizes publications and does not encourage the recording of other creative activities such as works art or patents.

Also the present system of manila folders does not provide the capability to economically search for publications of a certain type, subject, or year of origin. The proposed system could do all of this and more.

In addition to minimizing the faculty effort required to keep all the various files current, it will provide a standardized form that each faculty member can retain for his own records to assist in preparation of grant requests and other application forms.

A. Record Design

The publication record is a 300-character record which will contain the title, data, and publisher and co-author of each work. In addition, a system of coding works as to type and subject area will be included to classify the activity and to provide machine search capabilities. This will allow the record file to be searched and lists compiled chronologically, by department, type of activity, subject area, rank, or any combination of these variables. Proposed categories of creative faculty activities include:

01. Book
02. Paper
03. Review
04. Abstract
05. Monograph
06. Pamphlet
07. Work of Art
08. Journal Article
09. Dissertation (m)
10. Dissertation (d)
11. Office Report
12. Radio or TV Participation
13. Editorship
14. Grant Request
15. Report (contract research)
16. Invention/Patent
17. Other

The proposed form is shown on page 244, Figure 4:2. VII.

B. Creation and Maintenance

Two copies of the above mentioned form (Figure 4:2. VII) will be sent to each new faculty member. The faculty member fills out the form in duplicate, retains one copy for his records, and returns the other copy to the central faculty records office. The returned copy is the source document for the creation of the machine record and is then filed in the individual's folder in the central faculty office. This provides ready access to any individual's record without the expense and delay of consulting the tape file for just one record. Maintenance is accomplished once a year by sending to each faculty member two copies of what is stored in the tape file and asking him to make any additions and/or corrections. One copy is again retained by the individual and the other returned to the central office to allow updating of the tape record. The copy returned by the individual then replaces the old folder copy. Thus, a chronological record of creative activities is accumulated on the tape and in the folders for each faculty member.

C. Reports

In addition to the search and special report capabilities, the publications tape file lends itself to a number of possible routine reports. Among these are:

1. Annual report of publications and creative activities
2. Dissertation titles of faculty members
3. Report of research activities
4. Publication in the health-related fields
5. Research experience of M. S. U. faculty
6. Publications related to international activities (Midwest Universities Consortium for International Activities)
7. A chronological listing of books published by faculty members

4. Budget-Payroll-Deduction Record (BPD)

This record is designed to be integrated into the present organizational structure of the university and at the same time take advantage of the machine processing capabilities available in the new IBM S/360.

The basic component of this record system is a machine-addressable record stored on a 2311 disk file. The 2311 is a random access storage device capable of storing up to 18,000 314-character records. Any individual record can be consulted in a matter of seconds at any of the designated remote locations.

Interrogation is accomplished through the 1052 remote typing unit and 2260 visual display unit installed at each processing location.

A. Record Design

The record itself consists of four sections that will facilitate the creation and maintenance of the file. The four sections are: (1) identification, (2) budget-planning, (3) payroll-accounting, and (4) deductions-benefits.

The contents of each section are briefly described on pages 246 and 247, Table 4:2. I. The record design will eliminate some of the present duplication of data and eliminate the need for cards altogether. In addition, various reports and planning information, not previously available due to the separation of the records, will become available.

B. Creation and Maintenance of Records

Creation and maintenance of the BPD record is accomplished at the remote typer keyboard. The information is typed in a prescribed format, and as a result a record is created or updated. The visual display provides a check on what is written on the record, and in the case of record maintenance it displays the original record to facilitate updating. In the event of a termination, the entire record may be erased from the keyboard.

C. Creation of Advance Records

The design of this record will allow the creation of records for appointments that are effective at a later date. These records will be written with an effective date and coded as inactive until that time. Termination dates will be carried on all pertinent records in addition to the effective date.

This will allow the calculation of encumbered salaries and permit reports to be compiled as of some future dates. Terminated records will be ignored after the termination date but will not be erased until specific steps are taken to do so from the keyboard or by a maintenance routine.

D. Record Security

Unauthorized access to the records in the BPD file can be prevented by three methods, all of which may be used to prevent compromise of the records.

The first method is to allow only the typers at the BPD processing stations to interrogate the file. All other units would be electronically locked out.

The second method is by use of code words. Access to the file is permitted only if the correct code word is included in the request for information. Code words could be changed as often as necessary to insure security.

The third method is an extension of the code word protection system which requires that a sequenced number be entered when a request is made of the file. This code number is incremented each time the file is interrogated. Thus, the next request must include a new code number, i. e., one higher than the last number.

All three of these methods may be used simultaneously to prevent unauthorized access to the file. To gain access to any record in the file, the interrogator must be at the proper keyboard, know the code word, and be aware of the next sequence number. There are probably easier ways to obtain the information than to second guess the system.

E. Residence Programs

Residence programs are defined as on-line programs stored in memory which are over and above the control programs required to create, maintain, and delete individual records. Further, a residence program is used to create, summarize, and generate reports or run trial balances and may be set in motion from the typer keyboard.

Programs that may be in residence include head count and F. T. E. F. by rank and department and trial balance on payroll runs.

Both the residence and control programs will be available when the BPD file is on-line.

The issuance of pay checks and associated accounting functions requiring additional tapes and/or large amounts of printing will be handled in the normal manner by Data Processing. The BPD file will serve as input to the payroll and account distribution routines replacing the salary, reductions, and deductions cards that now provide the input. When the payroll is run, the terminated records will be deleted, advance records that become effective next payroll will be sequenced, and general housekeeping will be accomplished. The old file will be dumped on tape and preserved in the vault to serve as back up to the on-line file.

The issuance of pay checks of similar production runs could not be initiated from the typer keyboard.

The Central Faculty Office

The concept of a Central Faculty Office is one of a small administrative group specifically charged with the collection, coding, storage and distribution of the data contained in the biographical and publication records. This would eliminate much duplication of effort that now occurs in the collection and storage of faculty data. The total advantage is greater than the elimination of the duplication of effort. It involves a concept of complete, accurate, and comprehensive information in a centralized, coordinated and machine-addressable record storage.

The office itself might be considered to be a logical extension of the Secretary of the Faculties Office; however, its close working relationship with the Office of Institutional Research and the Faculty Staff Budget Office seems to indicate that a closer affiliation with the Provost's Office may be desirable.

As indicated earlier it seems that the Office of Institutional Research and Budget-Payroll Offices are in a position to implement the Current Activities and the Budget-Payroll-Deduction Records, respectively. The development of these latter two records could start immediately and does not rely on the establishment of a formal organization.

Conclusion

This proposed system is designed to improve the collection, storage and distribution of faculty data. The benefits that accrue to the university can be many, not only in the areas of gross data and ease of reporting but in the internal day-to-day operations of the university.

A university system of common codes and classifications would facilitate the internal transfer of data and eliminate much of the conversion, recoding and manipulation that occurs when basic data is transmitted across organizational lines within the university. This proposed system of a more organized and centralized faculty data collection would free many of the university offices now presently enmeshed in data collection to engage in their primary task.

It is believed that this system will provide a faculty data base of sufficient depth and breadth to handle all anticipated requests for data in any form and on a gross or individual basis. Standard report programs will be written to support the system, and special requests can be honored with minimal programming. Additional benefits of the system are:

1. The faculty will not be required to complete a diversity of questionnaires asking similar information.
2. Gross data will be readily available and in some areas for the first time, particularly in the area of faculty resources.
3. The system will be able to generate "management reports" to aid in planning and reporting.
4. The university will be able to fulfill its obligation to EDUCOM, the State Technical Services, and similar endeavors in the faculty area.
5. Central control of the collection and the reporting of data will result in more complete, accurate, and consistent information.
6. Internal data transfer across organizational lines within the university will be improved.

In the complete system the individual records are designed to complement each other to provide a comprehensive data base. However, it should be pointed out that each of the four records are essentially independent of each other. Thus, it is possible and perhaps desirable that the records be developed one at a time with emphasis on the most critical areas.

The time to start is now. The details and implementation of any good system takes time. The university has the opportunity to take advantage of the tremendous capabilities available in the new IBM 360 if development can be started soon.

If this proposal does no more than suggest to the university that it should take a hard look at the manner in which faculty data is collected and transmitted within the university, then it will have been worth the effort.

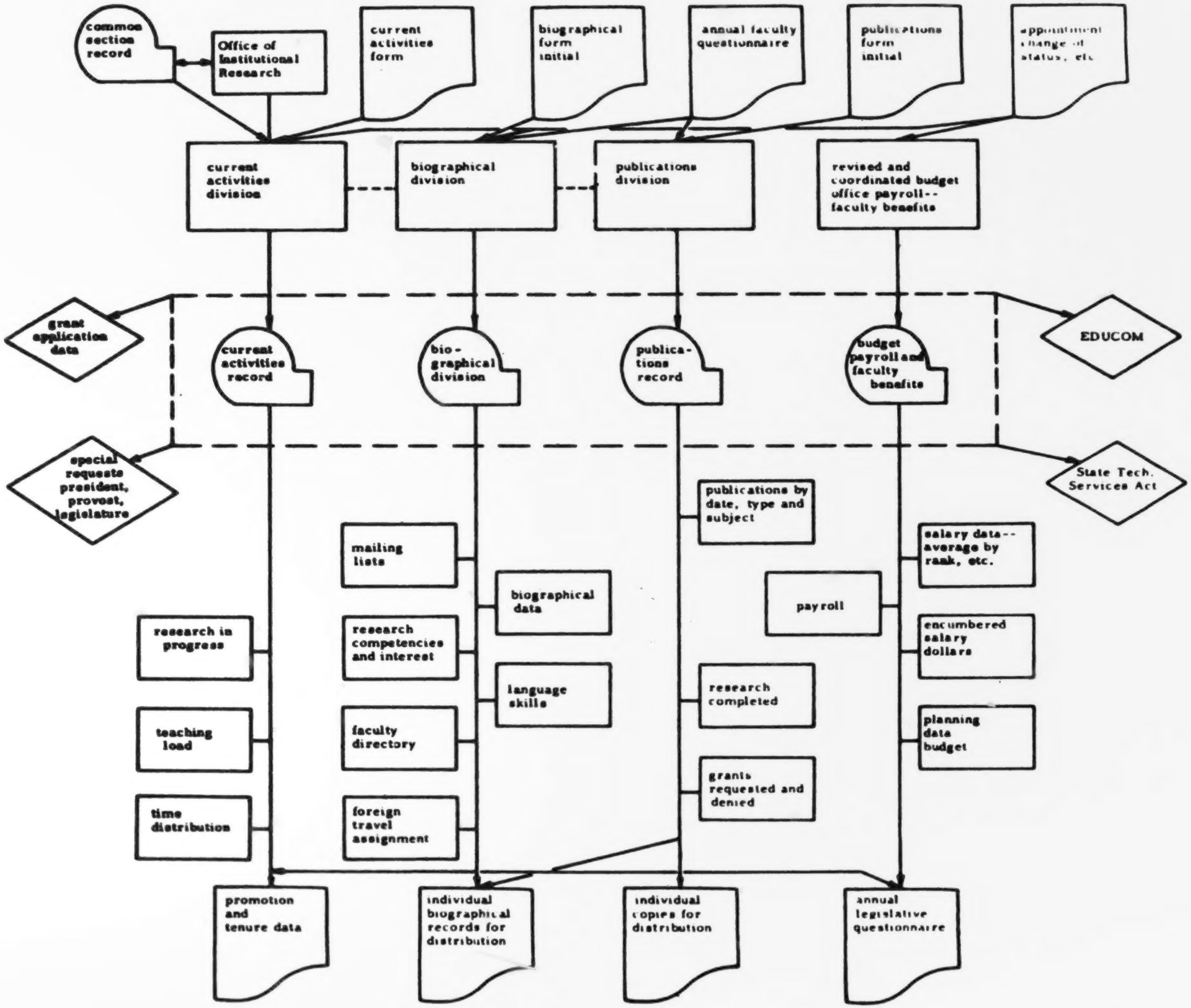
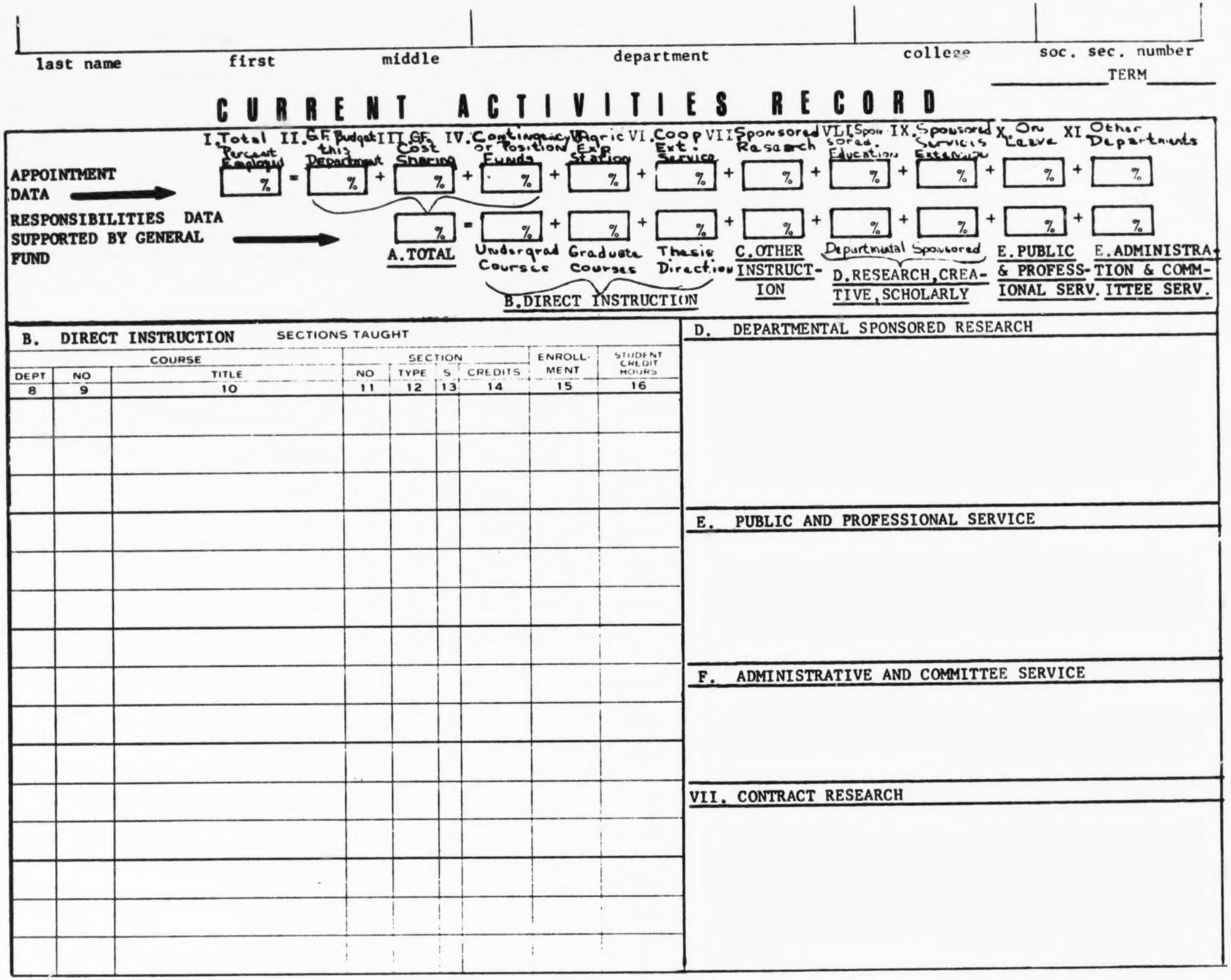

common section record
Office of Institutional Research
current activities form
biographical form initial
annual faculty questionnaire
publications form initial
appointment change of status, etc
current activities division
biographical division
publications division
revised and coordinated budget office payroll-- faculty benefits
grant application data
current activities record
bio-graphical division
publica-tions record
budget payroll and faculty benefits
EDUCOM
special requests president, provost, legislature
State Tech. Services Act
publications by date, type and subject
mailing lists
salary data-- average by rank, etc.
biographical data
payroll
research in progress
research competencies and interest
encumbered salary dollars
language skills
research completed
teaching load
faculty directory
planning data budget
grants requested and denied
time distribution
foreign travel assignment
promotion and tenure data
individual biographical records for distribution
individual copies for distribution
annual legislative questionnaire

Figure 4:2-I Central Faculty Record Concept.



last name first middle department college soc. sec. number

TERM

CURRENT ACTIVITIES RECORD

APPOINTMENT DATA →
I. Total Percent Employed % = II. G.F. Budget this Department % + III. G.F. Cost Sharing % + IV. Contingency or Position Funds % + V. Agric Exp Station % + VI. Coop Ext. Service % + VII. Sponsored Research % + VIII. Sponsored Education % + IX. Sponsored Services Extension % + X. On Leave % + XI. Other Departments %

RESPONSIBILITIES DATA SUPPORTED BY GENERAL FUND →
A. TOTAL % = Undergrad Courses % + Graduate Courses % + Thesis Direction % + C. OTHER INSTRUCTION % + Departmental % + Sponsored % + E. PUBLIC & PROFESSIONAL SERV. % + E. ADMINISTRATION & COMMITTEE SERV. %

B. DIRECT INSTRUCTION

D. RESEARCH, CREATIVE, SCHOLARLY

B. DIRECT INSTRUCTION SECTIONS TAUGHT

COURSE			SECTION				ENROLL-MENT	STUDENT CREDIT HOURS
DEPT	NO	TITLE	NO	TYPE	S	CREDITS		
8	9	10	11	12	13	14	15	16

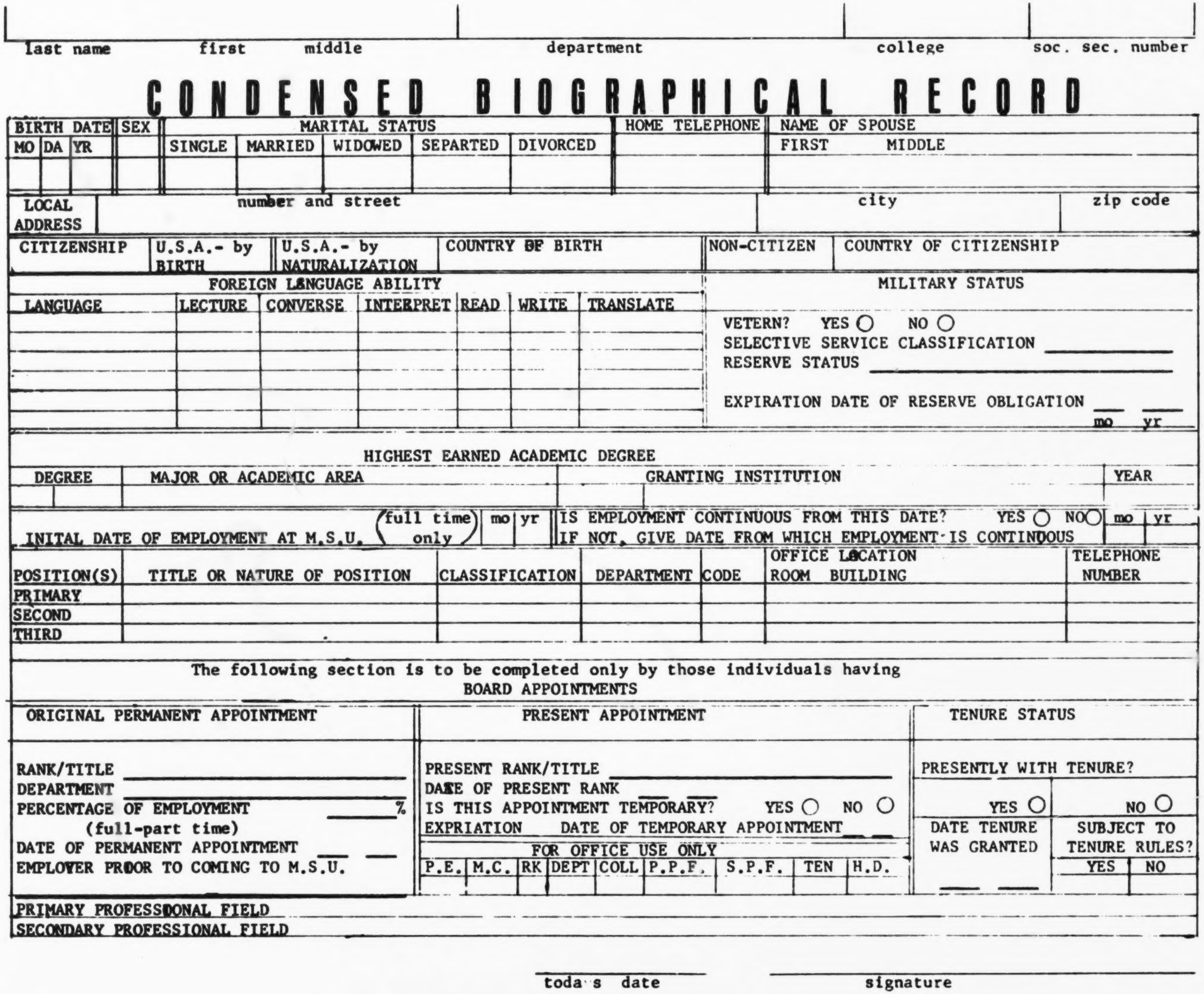
D. DEPARTMENTAL SPONSORED RESEARCH

E. PUBLIC AND PROFESSIONAL SERVICE

F. ADMINISTRATIVE AND COMMITTEE SERVICE

VII. CONTRACT RESEARCH

Figure 4:2-II Current Activities Record



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CONDENSED BIOGRAPHICAL RECORD

BIRTH DATE			SEX	MARITAL STATUS					HOME TELEPHONE	NAME OF SPOUSE	
MO	DA	YR		SINGLE	MARRIED	WIDOWED	SEPARTED	DIVORCED		FIRST	MIDDLE

LOCAL ADDRESS	number and street	city	zip code

CITIZENSHIP	U.S.A.- by BIRTH	U.S.A.- by NATURALIZATION	COUNTRY OF BIRTH	NON-CITIZEN	COUNTRY OF CITIZENSHIP

FOREIGN LANGUAGE ABILITY

LANGUAGE	LECTURE	CONVERSE	INTERPRET	READ	WRITE	TRANSLATE

MILITARY STATUS

VETERN? YES ○ NO ○

SELECTIVE SERVICE CLASSIFICATION ____________

RESERVE STATUS ____________

EXPIRATION DATE OF RESERVE OBLIGATION ___ ___
mo yr

HIGHEST EARNED ACADEMIC DEGREE

DEGREE	MAJOR OR ACADEMIC AREA	GRANTING INSTITUTION	YEAR

INITAL DATE OF EMPLOYMENT AT M.S.U. (full time only)	mo	yr	IS EMPLOYMENT CONTINUOUS FROM THIS DATE? YES ○ NO ○ IF NOT, GIVE DATE FROM WHICH EMPLOYMENT IS CONTINUOUS	mo	yr

POSITION(S)	TITLE OR NATURE OF POSITION	CLASSIFICATION	DEPARTMENT	CODE	OFFICE LOCATION ROOM BUILDING	TELEPHONE NUMBER
PRIMARY						
SECOND						
THIRD						

The following section is to be completed only by those individuals having
BOARD APPOINTMENTS

ORIGINAL PERMANENT APPOINTMENT

RANK/TITLE ____________

DEPARTMENT ____________

PERCENTAGE OF EMPLOYMENT (full-part time) ______%

DATE OF PERMANENT APPOINTMENT ___ ___

EMPLOYER PRIOR TO COMING TO M.S.U.

PRESENT APPOINTMENT

PRESENT RANK/TITLE ____________

DATE OF PRESENT RANK ___ ___

IS THIS APPOINTMENT TEMPORARY? YES ○ NO ○

EXPRIATION DATE OF TEMPORARY APPOINTMENT ___ ___

FOR OFFICE USE ONLY

P.E.	M.C.	RK	DEPT	COLL	P.P.F.	S.P.F.	TEN	H.D.

TENURE STATUS

PRESENTLY WITH TENURE?

YES ○	NO ○
DATE TENURE WAS GRANTED ___ ___	SUBJECT TO TENURE RULES? YES NO

PRIMARY PROFESSIONAL FIELD

SECONDARY PROFESSIONAL FIELD

______________ toda's date

______________ signature

Figure 4:2-III Condensed Biographical Record

last name first middle	department	college	soc. sec. number

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EDUCATION

		ATTENDED							DEGREE GRANTED	
		FROM		TO						
	NAME AND LOCATION	mo	yr	mo	yr	MAJOR FIELD	MINOR FIELD	DEGREE	mo	yr
SCHOOL UNDERGRADUATE	1.									
	2.									
GRADUATE AND PROFESSIONAL	1.									
	2.									
	3.									
POST-DOCTORAL	1.									
	2.									

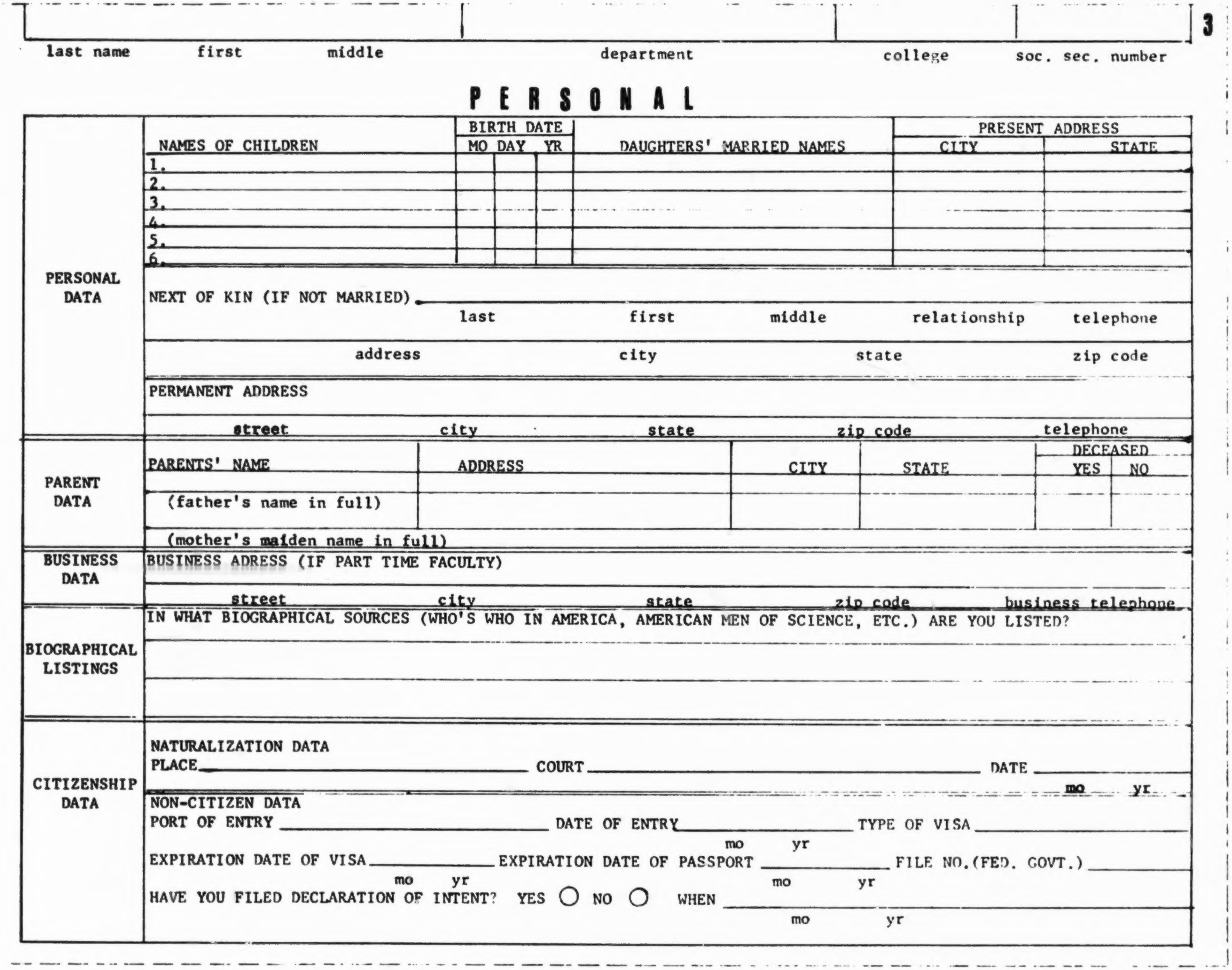
		FROM		TO		
FELLOWSHIPS	AWARDED BY	mo	yr	mo	yr	PURPOSE
	1.					
	2.					

		DATE		
HONORS, AWARDS OR HONORARY DEGREES	AWARDED BY	mo	yr	TYPE OF AWARD
	1.			
	2.			

		GRANTED		EXPIRES		
PROFESSIONAL REGISTRATIONS, LICENSES, CERTIFICATIONS	TYPE	mo	yr	mo	yr	GEOGRAPHICAL LIMITATIONS
	1.					
	2.					

		DATE OF ADMISSION			FROM		TO	
MEMBERSHIPS AND POSITIONS IN HONORARY, LEARNED, AND PROFESSIONAL ORGANIZATIONS	NAME OF ORGANIZATION	mo	yr	OFFICES HELD	mo	yr	mo	yr
	1.							
	2.							
	3.							

Figure 4:2-IV Education Record



last name first middle department college soc. sec. number

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PERSONAL

PERSONAL DATA

NAMES OF CHILDREN	BIRTH DATE MO	BIRTH DATE DAY	BIRTH DATE YR	DAUGHTERS' MARRIED NAMES	PRESENT ADDRESS CITY	PRESENT ADDRESS STATE
1.						
2.						
3.						
4.						
5.						
6.						

NEXT OF KIN (IF NOT MARRIED)

last first middle relationship telephone

address city state zip code

PERMANENT ADDRESS

street city state zip code telephone

PARENT DATA

PARENTS' NAME	ADDRESS	CITY	STATE	DECEASED YES	DECEASED NO
(father's name in full)					
(mother's maiden name in full)					

BUSINESS DATA

BUSINESS ADRESS (IF PART TIME FACULTY)

street city state zip code business telephone

BIOGRAPHICAL LISTINGS

IN WHAT BIOGRAPHICAL SOURCES (WHO'S WHO IN AMERICA, AMERICAN MEN OF SCIENCE, ETC.) ARE YOU LISTED?

CITIZENSHIP DATA

NATURALIZATION DATA

PLACE ______ COURT ______ DATE ______ mo yr

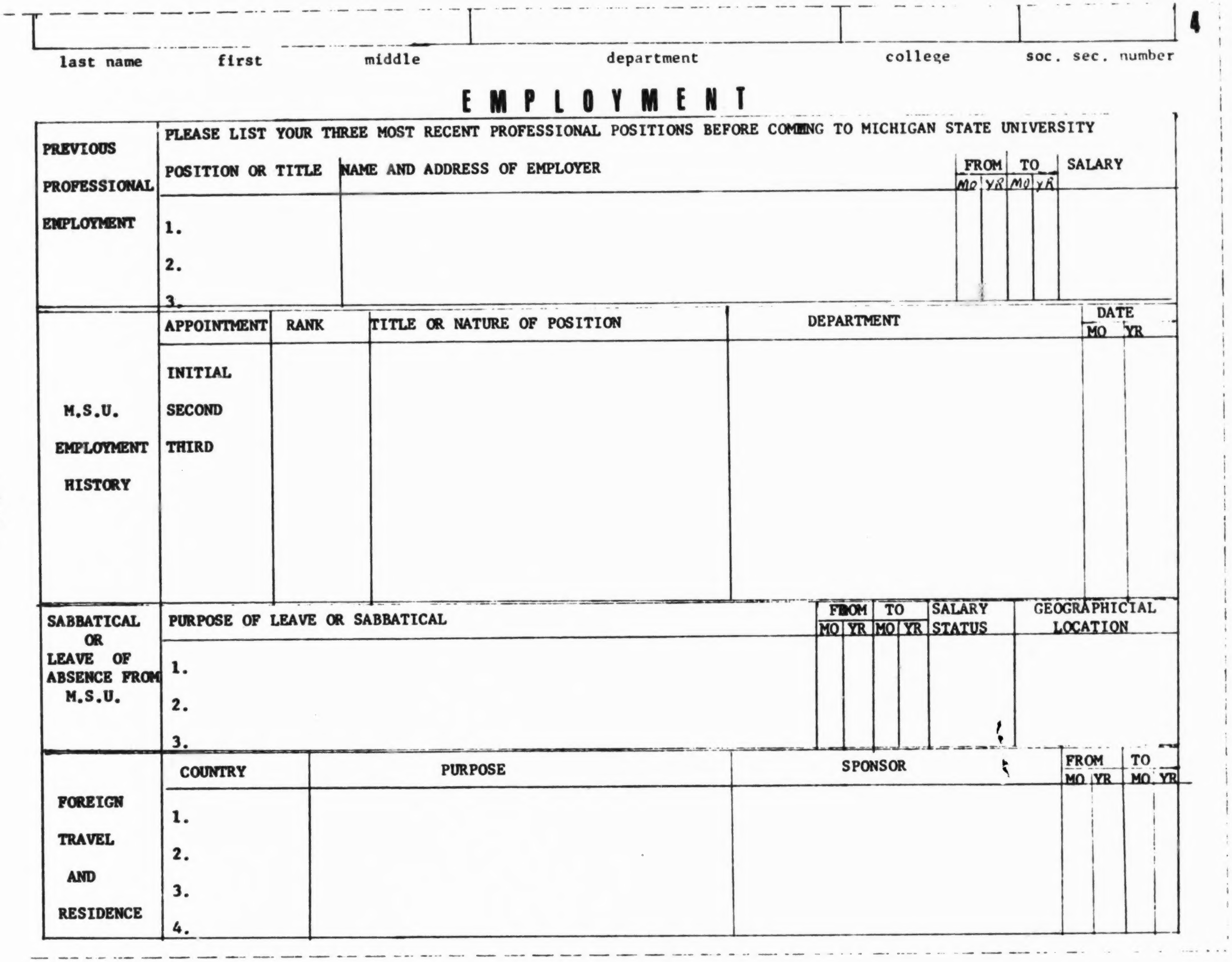
NON-CITIZEN DATA

PORT OF ENTRY ______ DATE OF ENTRY ______ mo yr TYPE OF VISA ______

EXPIRATION DATE OF VISA ______ mo yr EXPIRATION DATE OF PASSPORT ______ mo yr FILE NO.(FED. GOVT.) ______

HAVE YOU FILED DECLARATION OF INTENT? YES ○ NO ○ WHEN ______ mo yr

Figure 4:2-V Personal Record



4

last name	first	middle	department	college	soc. sec. number

EMPLOYMENT

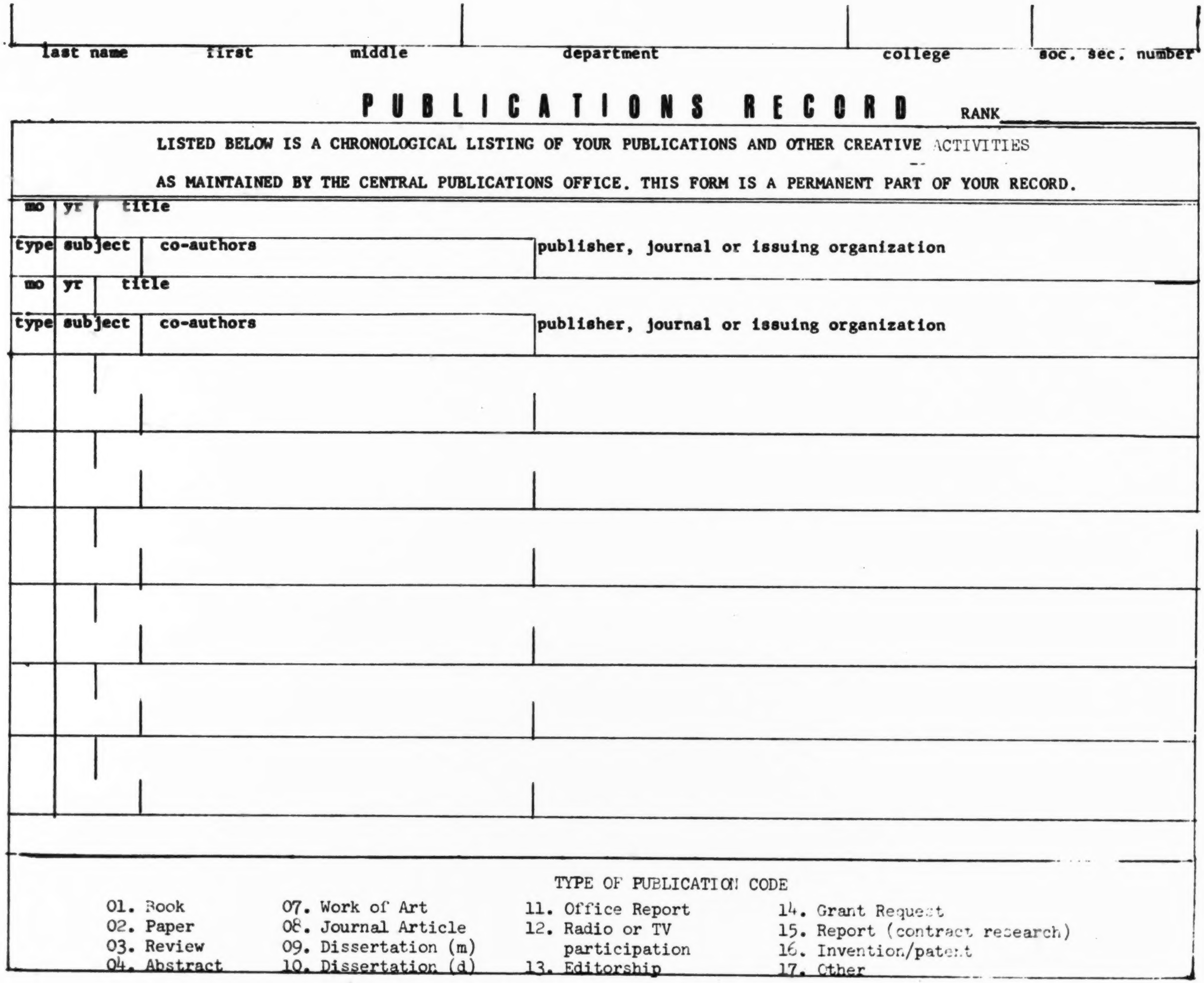
PREVIOUS PROFESSIONAL EMPLOYMENT	PLEASE LIST YOUR THREE MOST RECENT PROFESSIONAL POSITIONS BEFORE COMING TO MICHIGAN STATE UNIVERSITY						
	POSITION OR TITLE	NAME AND ADDRESS OF EMPLOYER	FROM		TO		SALARY
			MO	YR	MO	YR	
	1.						
	2.						
	3.						

M.S.U. EMPLOYMENT HISTORY	APPOINTMENT	RANK	TITLE OR NATURE OF POSITION	DEPARTMENT	DATE	
					MO	YR
	INITIAL					
	SECOND					
	THIRD					

SABBATICAL OR LEAVE OF ABSENCE FROM M.S.U.	PURPOSE OF LEAVE OR SABBATICAL	FROM		TO		SALARY STATUS	GEOGRAPHICIAL LOCATION
		MO	YR	MO	YR		
	1.						
	2.						
	3.						

FOREIGN TRAVEL AND RESIDENCE	COUNTRY	PURPOSE	SPONSOR	FROM		TO	
				MO	YR	MO	YR
	1.						
	2.						
	3.						
	4.						

Figure 4:2-VI Employment Record



last name first middle department college soc. sec. number

PUBLICATIONS RECORD RANK

LISTED BELOW IS A CHRONOLOGICAL LISTING OF YOUR PUBLICATIONS AND OTHER CREATIVE ACTIVITIES AS MAINTAINED BY THE CENTRAL PUBLICATIONS OFFICE. THIS FORM IS A PERMANENT PART OF YOUR RECORD.

mo yr title

type subject co-authors publisher, journal or issuing organization

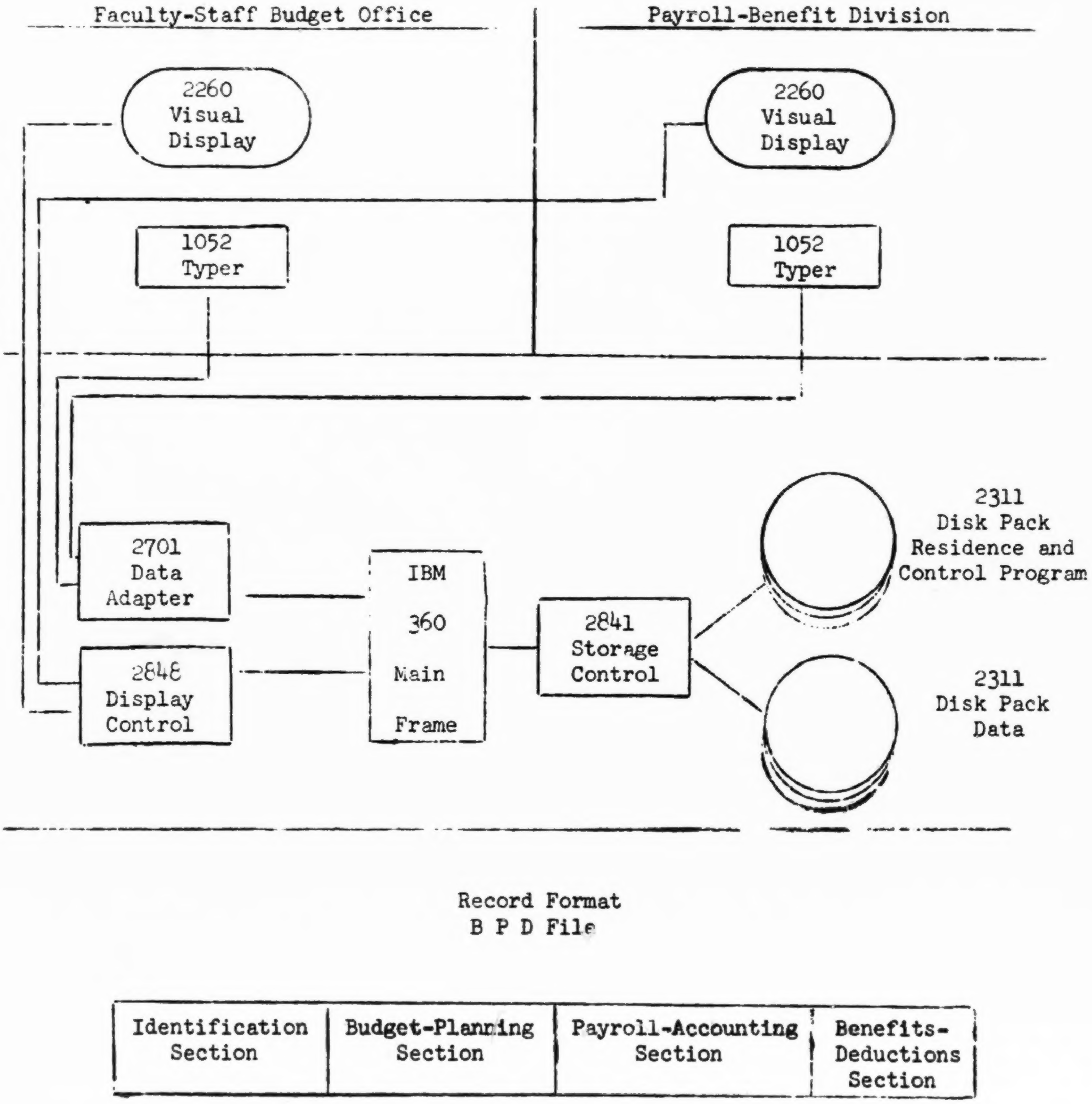
mo yr title

type subject co-authors publisher, journal or issuing organization

TYPE OF PUBLICATION CODE

01. Book
02. Paper
03. Review
04. Abstract
07. Work of Art
08. Journal Article
09. Dissertation (m)
10. Dissertation (d)
11. Office Report
12. Radio or TV participation
13. Editorship
14. Grant Request
15. Report (contract research)
16. Invention/patent
17. Other

Figure 4:2-VII Publications Record


Faculty-Staff Budget Office
Payroll-Benefit Division
2260 Visual Display
2260 Visual Display
1052 Typer
1052 Typer
2701 Data Adapter
2848 Display Control
IBM 360 Main Frame
2841 Storage Control
2311 Disk Pack Residence and Control Program
2311 Disk Pack Data

Record Format
B P D File

Identification Section	Budget-Planning Section	Payroll-Accounting Section	Benefits-Deductions Section

Figure 4:2-VIII Record System Flow Chart

Table 4:2-I Budget and Payroll Format

BUDGET - PAYROLL - DEDUCTION
2311 DISK FILE

RECORD FORMAT

I. IDENTIFICATION SECTION

Item	Position
1. Social Security Number	9
2. Name	18
3. Rank/Title	3
4. Payroll Master Information	55
	85

II. BUDGET-PLANNING SECTION

1. % Employment (University)	3
2. % General Fund	3
3. Employment Basis (months)	2
4. Payroll Month (9, 10, or 12)	2
5. Effective Date (Advance record)	6
6. Termination Date	6
7. Gross Annual Salary	7
8. Special Remarks Code	2
	31

III. PAYROLL-ACCOUNTING SECTION

1. Account Number	6
2. Department Code	3
3. Position Number	4
4. % This Account	3
5. Salary This Account	7
	23
FOUR ADDITIONAL SECTIONS	92
	115

IV. DEDUCTIONS-BENEFITS SECTION

1. Salary Reduction	7
2. Reduced Gross Amount	7
3. Number of Departments (True)	2
4. TIAA/CREF 1X Account	9
5. TIAA/CREF 2X Account	9
6. TIAA/CREF 3X Account	9
7. TIAA/CREF 4X Account	9
8. TIAA/CREF 5X Account	9
9. Medical Plan Code	2
10. Medical Plan Deduction	6

DEDUCTIONS-BENEFITS SECTION (cont'd)

	Position
11. Major Medical	1
12. Major Medical Deduction	6
13. Community Chest Deduction	6
14. Parking Deduction	4
15. Credit Union Deduction	6
16. Life Insurance Deduction	6
17. Social Security Deduction	6
18. Number of Dependents (Federal Income Tax)	2
19. Federal Income Tax	6
20. Other Deductions (Code and Amount)	6
21. Other Deductions (Code and Amount)	6
22. Other Deductions (Code and Amount)	6
	130
Total Positions	361

Maximum number of records per track	8
Maximum number of records per file	16,000

Table 4:2-II Faculty Record Data Summary

	CURRENT ACTIVITIES RECORD	BIOGRAPHICAL RECORD	PUBLICATIONS RECORD	BUDGET-PAYROLL RECORD
Type of Storage	Magnetic Tape	Magnetic Tape	Magnetic Tape	2311 Disc File
Storage Capacity	34,560,000 Characters	34,560,000 Characters	34,560,000 Characters	7,250,000 Characters
Record Size	2,000 Characters	1,110 Characters	300/Publication	361
Maximum Number of Records	13,930 Unblocked	21,600 Unblocked	43,200 Unblocked	16,000
Collection & Maintenance	Office of Institutional Research	Central Faculty Office	Central Faculty Office	Budget-Payroll
Create Record	End of First Term	Appointment	Appointment	Appointment
Up-Date	Each Term	Annual (Spring)	Annual (Late Summer)	Current
Employees	All Faculty	All Employees (1st page) "A" Faculty & A.P. (pages 2-4)	"A" Faculty & A.P. and Selected Other	All Employees
Printed	End of Term	At Annual Up-Date	At Annual Up-Date	As required to keep current
Contents and Derived Reports	Teaching Load Time Distribution Research in Progress	Biographical Data Language Skills Faculty-Staff Directory Professional Field Mailing Lists Campus and Home -- Highest Degree	Publications... By Date, Type, & Subject Research Completed Grant Requests	Payroll Salary Data --- Average by Rank, etc Encumbered Salary Dollars Budget Planning Data

4:3 Program STUVEC

prepared by

M. G. Keeney
J. Fowler

4:3 Program STUVEC

Initially, the purpose of the program STUVEC is described followed by a detailed description of its several parts, including available outputs, the operating procedures, and data. A documented listing of the program and a sample run is included in a separate binding as in 4:3. 5.

4:3. 1 Purpose of STUVEC

The purpose of this program is to produce a matrix and set of vectors that represent the changes in the student population over a given period of time (e. g., 1 term, 1 year).

At present the program produces a transition maxtrix and vectors for students dropped, students graduated, absent graduate students, new students, transfer students, re-enrolled students, total input, and total output. In the model the total input vector (which is the sum of new students, transfer students, and re-enrolled students) has usually been used. Dropped, graduated, and absent graduate students are added together to make the total output vector.

Each curriculum is assigned to one of sixteen fields, and each class rating is assigned to one of six levels. Actually, the numbers of fields and levels are arbitrary and are limited only by memory space. Consequently, they can be changed if necessary.

Since each student has a curriculum and class, he can be assigned a field-level category. The subscript of any vector or matrix represents a given category (or field-level). The field-level is assigned by using the following formula:

(FLD-1)* LEVEL + LVL

where

FLD is the assigned field,

LVL is the assigned level, and

LEVEL is the total number of levels.

The transition matrix represents the change in a student's field-level from one selected point in time to another later point in time. The column number of the matrix represents the student's field-level at the first point in time,while the row number represents his field-level at the second point in time. The value of an entry of the matrix represents the number of students who have made that particular field-level transition.

The Student Dropped vector, the Graduated Student vector, and the Graduate Student Absent vector represent those students who are present at the first point in time but not at the second point in time. All graduate students who are in this category are placed in the Graduate Student Absent vector in the entry representing his field-level at that time. No distinction is made about their status as to dropped or graduated. All undergraduates are declared either graduated or dropped. Those who have a certain number of credits are said to have graduated while those students with less than this number are said to have dropped. This method was used here since the Student Master Record does not indicate when a student graduates.

The New Student vector, the Transfer Student vector, and the Re-enrolled Student vector represent those people who were here at the second point in time but not at the first point in time.

4.3.2 Description of STUVEC

In the operation of this program, it is assumed that student numbers are arranged in ascending order on the tapes. A student record is read from each tape and the student numbers are compared. If they are the same, that student's field-level is determined for each period in time, and the proper entry in the transition table is augmented by one. Another record is then read from each tape, and the loop continues.

If the two student numbers are different, the smaller of the two is considered. If the student is from the first point in time (i.e., the first tape), then he has left the system during the time period being considered and must be placed in the dropped, graduate or graduate student absent vector. If the student is from the second point in time (i. e., the second tape), he has entered the system during the time under consideration and must be placed in the new, transfer, or re-enrolled vector. In either case, the proper entry is augmented and another student record is read from the same tape and the student numbers are compared as before.

When the end of one of the tapes is reached, the student number is set to 999999, and processing continues until the other tape is finished. All the data retrieved is then printed and/or punched as determined by the parameters supplied by the user.

Program (STUVEC) consists of 5 subroutines, DECODE, INCODE, RTNFLDLV, PRINTER1, PRINTER2, and 5 sections: preliminary, main, new student, parity error, and output. Efficient processing would dictate that some of these be written in assembly language (which actually was done), but for compatibility and communication purposes a FORTRAN version of all programs is described here.

The preliminary section reads in a set of working variables, the first of which come from the tape units on which the Student Master Records are stored (INPUT1, INPUT2). A record is immediately buffered in from each unit. Next to be read in are the printing and punching keys (IPRINT, IPUNCH), the printing keys for PRINTER1 and PRINTER2 (OPTION 1, -2,

-3, -4, -5), the number of fields and levels (IFIELD, ILEVEL), the class to level assignments, the titles for the fields and levels, and the printing formats for PRINTER1. For reference, these working variables are printed on the output. The number of categories (field-levels) is calculated. A call to INCODE causes the curriculum to field assignments to be read and an array CODE to be formed that relates curriculum-class to field-level. Check the documentation of INCODE for the method used.

The main section processes most of both tapes and forms the Transition matrix, the Dropped Student, Graduated Student, and Graduated Student Absent lists. It will also start the New Student, Transfer Student, and Re-enrolled Student lists. This section is divided into three subsections, two of which are nearly identical. These two return information about a student from each tape. The third compares the students and forms the vectors and the matrix.

Each physical record is broken into three student records by DECODE and six items (Student number, class, curriculum, total credits earned, admission status, and present status) are made available. The main section uses the same space for each student, so the items for the second and third student must be moved into place as needed.

The six item description for each student should be evident except admission status and present status. Present status differentiates between students that are returning (were enrolled the previous term), re-enrolled students, and students entering the school for the first time. For a given student this may vary from term to term. The admission status tells whether the student is a new or transfer student when he first entered. This datum, along with the student number, remains constant from term to term. The class, curriculum, and total credit report may change from term to term.

The program first calls for a record from tape INPUT1. The value of STU1 signals which student of the physical record must be used. (If STU1=1, a new record is needed and a check is made to see if the record has been buffered in (if not, wait until it is). If a parity error has occurred, it is processed in the parity error section. If an end-of-file has been read, control goes to the new student section. Otherwise check to see if the first character read is octal 17, an IBM end-of-file mark. If it is, control goes to the new student section, otherwise add one to the record count off INPUT1 and call DECODE to break up the physical record.) Reset STU1=2, and compare the student number against 999999. If it is larger, there is an error in the number, and both the record number and the unit number are printed. Go to the place where the second student's information is placed in the first student's variables. If it is 999999, the last record on the tape has been reached and processing continues in the new student section. If it is less than 999999, get the field-level and go to the beginning of the second student subsection.

If STU1=2 or 3, the second or third student's information is placed in the first student's variables respectively. STU1 is set equal to 3 or 1 respectively, and the student number is compared with 999999. If greater, the record number and the unit are printed and control goes to the third student transfer or the beginning of the subsection respectively; if equal, control goes to the new student section; if less, the field-level is obtained from RTNFLDLV and the second student request subsection is entered. This second subsection starts by checking ITAPE, to determine whether a record is needed from INPUT2. If equal to 1, skip the section; otherwise enter the subsection which is very much like the first to obtain a student record from the second tape. When an end-of-file is detected, the student number is set to all 9's, ITAPE is set to 1, and a jump is made to the third subsection. This allows the first tape to empty.

The third subsection begins by setting ITAPE equal to 0. The two student numbers are compared against each other. If the student number of tape INPUT1 is the smaller, the student dropped, graduated, or is an absent graduate student. If the student was a graduate student, he is placed in the graduate student absent vector. If a student wasn't a graduate student and had more than predetermined number of credits (ESGC=number of credits an engineer needs to graduate, RSGC=number of credits for a regular student to graduate), he is placed in the graduated vector; otherwise he is placed in the dropped vector. (Note: For several years engineers needed 208 credits to graduate instead of 180; therefore a distinction is made between engineers and "regular" students.) The element in the vector corresponding to the field-level is augmented by 1. In all the cases ITAPE is set equal to 1, and the program goes back to the first subsection. If the two students numbers are equal, then augment the element of the transition matrix whose row is the field-level of the second student and whose column is the field-level of the first student and go back to the first subsection. If the second student number is less, check the present status to see if he is a first-time student. If not, he is a re-enrolled student, so augment the vector in the proper element and return to the beginning of the second subsection; otherwise check the admission status to see if the student is a new student, a transfer student or a special. If he is a special student,print the information about him and return to the second subsection; otherwise augment the proper vector by 1 and return to the second subsection. If either the present status or the admission status is bad, print the bad status and return to the beginning of the second subsection.

When the new student section is entered, a check is made of ITAPE2. If it is 1, the program has already run out of students on the second tape, and it goes to the output section. Otherwise it enters the student check subsection which checks the admission status to see if the student is a new or transfer student and augments the correct vector. If the status is bad, or the student is a special student, this information is printed. Then control goes to the location for the first, second, or third student, depending on the value of STU2. Checks are made as described above for a completed buffer operation, parity error and end-of-file. Then DECODE is called to get the student's field-level, set STU2=2, and to get to the student check subsection above. If the second or third student is needed, the field-level is obtained, the second or third student's variables are transferred and STU2 is set to 3 or 1 respectively. If the student number equals 999999, control goes to the output section, otherwise to the student check subsection above.

In the parity error section, LOC1 will signal whether the parity error occurred on tape unit INPUT1 (1) or INPUT2 (0),and INPUT will be set equal to the bad unit. LOC2 will indicate which of the places an error occurred for unit INPUT2 (1-main section, second subsection, 0-new student section). A check is made to see how many times the reread was attempted, and if less than five times, the unit is backspaced one record and rebuffered; otherwise, the unit number and record is printed, the reread key reset to 0, and a new record buffered. Control is then returned for continued processing.

Subroutine DECODE decodes a physical record into the three student records which it contains. It is machine dependent in that a word length of 48 bits or 8 BCD characters is used. Shifting is accomplished by multiplication and division,and words are then masked to obtain the derived information. This method is superior to a FORTRAN DECODE statement (which is machine dependent) but inferior to an assembly language routine.

Each physical record contains the information for three students, and in Fig. 3:1. IV, the location of information used from that record is indicated.

The proper input tape is selected, as indicated by a calling parameter,and a check is made to ensure that there are no alphabetic characters in the student number. The values of the fields are then decoded and transferred to the proper location,and the reading of a new record into the buffer area is initiated.

Subroutine INCODE reads the curriculum to field assignments from the data deck, calculates the curriculum-class to field-level codes and stores them in array CODE. All entries in the CODE array are set to one more than the highest possible field-level. This leaves a space in each entry that doesn't get a new field-level to facilitate locating illegal curriculum class codes.

Next a data card is read. An arbitrarily assigned 3-character alphabetic code, the two characters of the university assigned alphanumeric code for each curriculum, and the curriculum's designated field are on the card. If the 3-character alphabetic code is *, the end of the data deck has been reached and transfer is made to the data-deck-ended section; otherwise, the data card is echo printed. The field, minus 1, is multiplied by the total number of levels. If this figure is greater than the total number of field-levels,a print is made to the effect that there is an improper field assignment, and a new data card is read. Otherwise, the university-assigned alphanumerics are checked for non-numerics and, if found, legal ones are converted to numerics. If an illegal character is found, a print is made to that effect, and a new data card is read. Otherwise the first character is multiplied by 10 and the second character is added to that. The result is again multiplied by 10.

The index of CODE is the result of the last operation plus a class. The value of CODE (index) is the field assigned to the curriculum minus one, times the number of levels, plus the level assigned to the class. This is done for each possible class. Next the alphabetic and alphanumeric information is stored in arrays, by field. After all the data cards have been processed, these arrays are printed to give the curricula by fields.

Integer Function RTNFLDLV is used to look up the field-level of a given curriculum-class combination.

First the curriculum is broken into two alphanumerics. The alphabetics are converted to numerics if they are legal alphabetics. Next the curriculum and class are checked to see if they are legal, and, if so, the correct field-level is returned. If the curriculum is illegal, but the class is legal, the field-level corresponding to the last field and correct level is returned. If the curriculum is illegal and the class is also illegal, the field-level of the last level in the last field is returned. If the curriculum is legal, but the class is illegal, the field-level of the last level in the correct field is returned. In all cases, the illegal codes will be printed. Anytime CODE is referenced, a check is made to see that it is between 1 and the number of categories, and if not, the field-level of the last level in the last field is returned. The curriculum-class code is calculated by taking the numeric value of the first character, multiplying this times 10 and adding the class. This is the index of CODE. CODE's value is the field-level for this curriculum class.

4:3.3 Output from STUVEC

The output of STUVEC includes an unmodified transition matrix and vectors representing the number of students dropped, the number graduated and the number of graduate students absent along with column totals of the matrix and the three vectors. It is possible to have zero suppression in the transition matrix and up to four significant figures. Each element can be divided by the column totals giving the decimal fraction for the transition matrix and the three vectors. This can be printed using zero suppression and/or with two significant figures after the decimal point. The percentage matrix and vectors may be punched without zero suppression, giving four significant places after the decimal point. All the vectors may be punched using the raw data. Percentage vectors created by dividing the elements in the vectors by their total may be printed and punched. Both printing and punching yield four places.

When output processing begins, the two tapes are rewound and all vectors are totaled. The transition matrix column totals give the number of students who stay in the system; an output vector is formed from the vectors of Dropped Student, Graduated Student, and Graduate Student Absent; an input vector is formed from the vectors New Student, Transfer Student and the Re-enrolled Student vectors; and the row totals of the transition matrix are formed. The term totals are calculated and printed along with the totals of the various vectors. An explanation of the abbreviations used in printing the transition matrix is given in the output. Next PRINTER1 is called twice with an OPTION call of 0, 1, or 3 (0 causes the subroutine to be skipped; 1 causes raw data to be printed without zero suppression; and 3 causes raw data to be printed with zero suppression). The transition matrix and the three vectors are divided by the column totals of the transition matrix plus the three vectors. PRINTER1 is again called twice with 0, 2, or 4 (0-skips the program; 2-prints the percentage data with zeros; 4-prints percentage data with zero suppression). PRINTER2 causes the vectors to be printed. It is called with 1, 2, or 3 (1 causes raw data to be printed and/or punched depending on IPRINT and IPUNCH; 2 causes percentage data to be printed and/or punched; 3 causes both to be printed and punched). Finally, if desired, all the percentage output of PRINTER1 is punched. (This is the transition matrix, the three vectors, the column totals, and the row totals.)

More explicitly, the output report contains statements indicating the input parameters that have been specified, diagnostic messages for any data that cannot be read correctly, and the output report desired, as detailed below.

The messages that report back the input parameters that have been specified should be examined to ensure that the requests have been interpreted as they were intended.

It is possible that the data tape will have become unreadable at certain points. The program makes several efforts to recover this information,but if it is unsuccessful, the offending record will be skipped with diagnostic messages such as:

(1) BAD PRESENT STATUS CODE A

```
STU. NO. 014379 CLASS 7 CURR 71 ADMISSION STATUS
```

This means that the record for student number 014379 who is in curriculum 71 at class level 7 and was admitted in status 3 (new, Master's Degree Candidate) has a non-readable Present Status code (which differentiates between returning, re-enrolled and new students).

(2) BAD ADMISSIONS CODE A

```
STU. NO. 265853 CLASS 3 CURR 31 PRESENT STATUS 2
```

The record for student 265853 has an unreadable Admission Status Code but is for a re-enrolled student (Present Status 2).

(3) PARITY ERROR ON UNIT 42, 4028 RECORDS OFF UNIT 42,
4285 RECORDS OFF UNIT 41

A parity error occurred on unit 42. At this time 4028 records had been processed from Unit 42 and 4285 from Unit 41.

Other such diagnostic messages are used for errors in various portions of the record. When such errors occur, these records are omitted from the processing and do not appear in the report output. But execution is not stopped, so subsequent records are properly processed. The user can then see which records were omitted and make a decision as to the usefulness of the report. The output report is then printed with suitable subtitles to indicate the various matrices.

Subroutine PRINTER1 prints the transition table and the Dropped, Graduated and Graduate Student Absent lists.

If OPTION = 0 or if IPRINT is 0, control is returned to the calling point, a do-loop is entered whose index is the first field printed across the section. The first and last field and field-levels to be printed across the section and the number of fields are calculated. Field titles are printed across the page. A do-loop is entered whose index is the particular field that will now be printed, and the field and level titles are printed. The field-level to be printed (row number) is calculated and the row (zero suppressed if specified by the OPTION call) is printed.

If the zero suppressor is entered, NLOC is set to 0. If the element is less than .005, the element is set to all blanks. If the element is between .005 and 1.00, the number is converted to BCD and output in 0.XX form where XX are the two most significant figures (it is rounded rather than truncated). If the number is greater than or equal to 1.00, it is converted to BCD in the form XXXX where XXXX are the last four significant places. If the number is too large, **** is output. Leading zeroes are turned into blanks and the element is then output under R-format. All printing of the PRINTER 1 is done by using variable formats. This procedure is continued until the section is printed, then the respective elements of the Dropped, Graduated, Graduate Student Absent, and column total vectors are printed. This is repeated for each section.

Subroutine PRINTER2 is used to print the various lists of number of new, transfer and re-enrolled students.

If OPTION 5 = 2 or IPRINT = 0, see the next paragraph. If OPTION 5 or 3, no further action is required and a return is made to the calling program. Otherwise the titles of the vectors and the entries of the various vectors for that field-level are printed. This continues for all field-levels; then the vector totals are printed.

If OPTION 2 or 3, a return is executed. Otherwise the percentages are formed by dividing each element by its respective column total. If IPRINT = 0, see the next paragraph. Otherwise the percentage elements of the vectors for that field-level are printed and this continues until all the field-levels are completed; then the column totals are printed.

If IPUNCH = 0, control is returned; otherwise the New, Re-enrolled, Dropped, Graduated, Graduate Student Absent, total input, and total output vectors and column totals are punched.

4:3.4 Use and Operation of STUVEC

To use the program, EQUIP cards and a data deck, or parameter deck, must be prepared.

The EQUIP cards are discussed in the CDC 3600 Drum SCOPE Manual and in MSU Computer Laboratory Notices No. 80, 148, 149, 167 and 178. Magnetic tape labels for Student Master tapes are given in 3:1 and particularly Fig. 3:1-I and 3:1-II. The EQUIP cards are inserted following the JOB Control Card, one each for the first and second terms and one for the results.

Card No.	Columns	Variable Name	Value
1	1-5	INPUT 1	Tape number, first term
	6-10	INPUT 2	Tape number, second term
2	If indicator is 0, the operation is inhibited, if 1, it is permitted		
	1-5	IPUNCH	PUNCH Results on Cards
	6-10	IPRINT	PRINT Results
3	0 inhibits, 1 permits the operation		
	1-5	OPTION 1	Raw Results With Zeros
	6-10	OPTION 2	Raw Results, Zero Suppression
	11-15	OPTION 3	Percentage Results With Zeros
	16-20	OPTION 4	Percentage Results, Zero Suppression
	21-25	OPTION 5	Number for PRINTER2 Call
4	1-5	IFIELD	Number of Fields
	6-10	ILEVEL	Number of Levels
5	1-10	ESGC	Credits Needed by Engineering Student to Graduate in Time Span Covered by the Two Tapes
	11-10	RSGC	Credits Needed by Non-Engineer
6	1-5	CLASS	Level Number for Class Code = 1
	6-10		Level Number for Class Code = 2
	...		
	...		Level Number for Class Code
	...		
	41-45		Level Number for Class Code = 9
7	1-4	LEVEL	Title for Level 1-4 BCD Characters

Card No.	Columns	Variable Name	Value
	5-8		Title for Level 2
	...		
	...		
	...		One 4-character title for each Level
8	1-5	FIELD	Title for Field 1
	5-10		Title for Field 2
	...		
	...		
	...		One 5-character title for each Field
9	1-8	FIELDS	Title for Field 1
	...		
	...		
	...		Title for Field One 8-character title for each Field Two cards will be required if there are more than 10 fields.
10-21		IFORMAT	Variable formats for PRINTER1, a set is supplied with the program
22-XX	1-3		Arbitrary 3-character curriculum code
	4-10		Blank
	11-12		University-assigned alphanumeric code
	13-15		Blank
	16-20		Field number to which curriculum is assigned

There should be one of these cards for each curriculum which is assigned to a field. Any curriculum encountered on the tapes which has not been assigned will be flagged as an error. The last card must have a 3-character code of * (i.e., a * in column 1 followed by blanks) to signify the end of the data deck. This final card must not have a curriculum to field assignment on it.

Fig. 4:3.4-I Parameter Deck Format for Program STUVEC

The parameter deck is prepared as detailed in Fig. 4:3.4-I and inserted following the RUN Control Card. A copy of the parameter deck is included with the program and may only require minor changes and verification for correct specifications before using.

4:3.5 Listing of STUVEC

A documented listing and a sample run of STUVEC is bound separated along with other computer programs.

4:4 Program CLASCARD

prepared by

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4:4 Program CLASCARD

This section consists of a description of CLASCARD, the output provided by it, and instructions for using it.

4:4.1 Purpose of CLASCARD

The purpose of the program is to obtain a matrix that shows the average number of credits a student majoring in a given field-level (or category) takes in each of the field-levels of the system.

Since each student has a class level (freshman, sophomore, etc.) and a curriculum major, he can be identified with a field-level category. The university curricula and classes need not be aggregated to the same number of fields and levels. The class card tapes contain all the class cards of all students in the university with each student's class cards grouped together and placed in numerical order according to student number. Each course has a department code from which the field is obtained. The first digit of the course number is used to assign the level. This gives each course a field-level category. See Fig. 3:1-VI for the Class Card Format.

When the student number changes on the tape, a new student is added to the number of students in the appropriate field-level list. For each class card, the number of credits is added to the matrix element whose column is the field-level of the student and whose row is the field-level of the course. After the tape has been completely read, each column in the maxtrix is divided by its corresponding element in the student field-level list. This yields the credits per field-level for a student in a given field-level category.

4:4.2 Description of CLASCARD

The program CLASCARD consists of a main program and five subprograms (READ, TRCDF, KTRCDF, MATRIX, PRINT).

The main program reads a title for the particular run and the run parameters. The parameters are: number of fields, levels, columns per class card, curriculum to field assignments, course number to level assignments, tape unit for the class card tape, unit for additional output, key for echo print, credit distribution matrix key, and credit/field-level for student/field-level matrix key. The total number of field-levels is calculated, and the number of words needed to buffer in a given record is set. The curriculum to field assignments, the class to level assignments, and the department to field assignments are read and echo printed if desired. A record is read into the initial buffer storage. The read subroutine returns either a new record, RD, in the working buffer storage or a 15 is entered in IEF if there are no records left. If no records remain, the print section of this program is entered; otherwise the record is broken up into 160 pieces of information, 8 pieces for each of the 20 class cards on the physical record. These eight values from a class card are transferred into new variables. (This will be done 20 times.) If the student number is all 9's, the field has been completed. For each class card detected, the total number of classes is augmented by 1. If the first digit of the course level is 0, it is an improvement course and the total number of improvement courses is augmented.

If the student number has changed, TRCDF is called, which returns the student's field-level given his curriculum and class. If the field-level is not 0, the student/field-level list is augmented for the student's field-level. If the field-level is 0, the curriculum or class was illegal and a new class card is obtained.

Next KTRCDF is called which returns the course's field-level, given the department code and first digit of the course number. Then the number of credits is calculated. This needs to be done since the BCD representation of a number sometimes is not equal to the actual value. Also blanks occur on the card. For example, 9 = 6011 in BCD, but it numerically should be 0011; next the number of credits for the class is added to the element of C whose row is the field-level of the course and column is the field-level of the student taking the course. This is repeated for each class card. Subroutine READ is used to read physical records, monitor for correct records, detect the end of the file and transfer the records to working storage. READ begins by setting the end-of-file indicator and parity error count to 0. A check is made to see if a record is in or to wait until it is. If it has a parity error on it, control is transferred to the parity error section; an end-of-file, IEF, is set to 15 and return executed (note, the first character will be placed in IEF and if 15, will not have to be set). The initial buffer storage is transferred to the working buffer storage, a new physical record is initiated for the initial buffer storage and control returned to the calling program.

The parity error section checks the parity error count to see if a reread has been done more than 5 times. If it has not, a reread is initiated. If it has, the physical record is listed, but the 20 class cards are lost from additional processing. The next physical record is then read and processing continues.

Function TRCDF looks up the field-level number for a given curriculum and class.

TRCDF begins by checking the curriculum code against the list of legal curriculums. If there is a legal one, the row it was in is saved; otherwise the bad curriculum and class are printed, the field-level set to 0, and control returned to the calling program.

Next the class code is checked against the list of all legal class codes. If there is one, the row is saved.

The second elements of the saved rows contain the field and level assigned to the curriculum and class. From these, the field-level is calculated.

Function KTRCDF has the same purpose as TRCDF except the course department and the course level are used instead of student curriculum and class.

4:4. 3 Output from CLASCARD

The general format of CLASCARD output is given in Fig. 4:4.3-I and diagnostic messages included in the report are explained in Fig. 4:4.3-II. After all of the class cards have been processed, the report title, number of improvement courses taken, total number of courses taken, and total number of students are printed, followed by a breakdown of the number of students in each field-level category. Flag M1 has been set to indicate whether or not to print the credit distribution matrix and if it is to be printed, subroutine PRINT is called with M = 1. Similarly, M2 is the indicator for the credit/student matrix and to print it, subroutine PRINT is called with M = 2. If an additional output unit was specified, subroutine MATRIX is called to print the credit/student matrix and the report is now completed.

```
CURRICULUM CODES ASSIGNED TO FIELDS
        Curriculum
        CODE                          FIELD
        set of codes                  their assigned fields
LEVELS OF STUDENTS
        CLASS                         LEVEL
        set of student classes        their assigned levels
DEPARTMENT ASSIGNED TO FIELDS
        DEPT.
        ABBREV.                       FIELD
        set of departments            their assigned fields
COURSES ASSIGNED TO LEVELS
        COURSE
        LEVEL                         LEVEL
        set of course levels          their assigned levels
TOTAL COURSES TAKEN  =  (number of valid class cards on tape)
IMPROVEMENT COURSES TAKEN  =  (number of class cards whose course
                               level is 0)
TOTAL NUMBER OF STUDENTS
TOTAL NUMBER OF STUDENTS IN EACH FIELD LEVEL
   (labeled vector, one element for each field-level category)
CREDIT DISTRIBUTION MATRIX
CREDITS PER STUDENT

Matrices are printed so that the column is the field level of the student taking
a course while the row number is the field-level of the course being taken.
Ex.             1      2      3      4
        1       x      x      x      x
        2      100     x      x      x       students in field-level 1 took 100
        3       x      x      x      x       credits of courses in field-level 2
        4       x      x      x      x
```

Fig. 4:4.3-I General Format of CLASCARD Output

_____IS AN UNDEFINED LEVEL ON RECORD_____
means that the program has found a student level not in the list of input student levels

_____IS AN UNDEFINED CURRICULUM ON RECORD_____
means that the program has found a student curriculum that is not on the list of input student curricula

_____IS AN UNDEFINED COURSE LEVEL ON RECORD_____
means that the program has found a course level not in the list of input course levels

_____IS AN UNDEFINED DEPT. CODE ON RECORD_____
means that the program has found a department code not in this list of input department codes.

The first blank is filled in with the offending data. Last blank contains the record of the bad data.

Fig. 4:4.3-II Diagnostic Messages in CLASCARD Output

Subroutine PRINT is used to print either the credit distribution matrix or the credit/student matrix. Since the page format of the report depends on the number of fields and levels, the values of these format parameters must first be calculated, then the proper column and row headings are printed, and finally all the matrix elements are encoded into BCD codes with zero appropriately replaced by a blank to get zero suppression.

Subroutine MATRIX prints the credit/student matrix on an additional unit when it is requested.

The record number and the output counter are set to zero. The matrix is written with 12 entries per record (except perhaps for the last one which may have zero fill to complete the line). After each record is output, the record number is incremented by 1.

Each element of the output buffer is loaded separately, and when the buffer is full, it is written out.

4:4.4 Use and Operation of CLASCARD

An EQUIP card for the term being processed must be inserted in the program deck following the JOB control card. References to information for preparing this card are given in 3:3.4.

The parameter deck is prepared as detailed in Fig. 4:4.4-I. As with STUVEC, a copy is included in the deck which may require only minor changes before a run is made.

Columns	Variable	Value
1st card		
1-80		title of run
2nd card		
1-5	NFLC	number of fields
6-10	NLEV	number of levels
11-15	NCOL	number of columns of a class card found on a record. 68 cols. - if no grades, 80 cols. - if grades
16-20	NCUR	number of curriculum-field assignments
21-25	NL2	number of student class-level assignments
26-30	NDEPT	number of department code-field assignments
31-35	NL4	number of course level-level assignments
36-40	LIN	tape unit that class card tape is on
41-45	LOU	output unit, = 0 if no additional output desired,
46-50	NECHO	key for data card echo print
51-55	M1	printing key for credit distribution matrix
56-60	M2	printing key for credit/student matrix
61-80		blank

Next comes a set of curriculum to field assignment cards.

Columns	Variable	Value
1-10		blank
11-12	L1	2 characters alphanumeric, university-assigned
13-15		blank
16-20		field curriculum is placed in
21-25		blank
26-57		comments
58-80		blank

Next a set of student level to level assignments.

Columns	Variable	Value
1-11		blank
12	L2	student level
13-15		blank
16-20		assigned level
21-25		blank
26-57		comments
58-80		blank

Next a set of department codes to fields.

Columns	Variable	Value
1-9		blank
10-12	L3	3 characters alphabetic code
13-15		blank
16-20		field department placed in
21-80		blank

Next a set of course level to level assignments.

Columns	Variable	Value
1-11		blank
12	L4	course level
13-15		blank
16-20		level that course level is placed in
21-25		blank
26-57		comments
58-80		blank

Fig. 4:4.4-I Parameter Deck Format for Program CLASCARD

4:4.5 Listing and Sample Run of CLASCARD

A documented listing and a sample run of CLASCARD are bound separately with other computer programs and results.

4:5 Computer Programs Based on the Model

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4:5 Computer Programs Based on the Model

4:5.1 An Implementation Feasibility Study

The purpose of the first program is to determine whether enough of the theoretical model can be incorporated in a working program to be a useful tool, and if so, to derive some idea of the programming effort that would be required, the size of the system that could be modeled, the computer size and speed constraints, the difficulties in printing meaningful yet concise reports, etc.

A working program was actually produced, though it was not very well developed before most of the considerations mentioned above were encouragingly answered. This program served as a point of departure for the development of MSUSIM and MSUSIM2, discussed in 4:5.2 and 4:5.3.

Small programs, using limited amounts of data, are useful for making gross calculations and can be developed in relatively little time. Larger programs, handling more data, can be realistic enough for making operating decisions, though the quality and inaccessibility of data impose a limit. Some consideration must be given to the mechanical control and processing of data files, and memory space will be the first constraint imposed by the computer. The presentation of results in a useful form, conveying all the necessary information, yet in a readily assimilated form continues to be one of the most challenging problems.

4:5.2 A Remote Terminal Program--MSUSIM

The primary purpose of the Remote Terminal program is to provide a vehicle for communicating with potential users. In order to develop a realistic model, it is essential to have information from these users as to their needs, the questions they must answer, the basis on which they make decisions, and their ideas as to how a model and its implementation might be useful. Further, if the program is useful, it must be understood by the user.

Other purposes, all related to the primary one, included the need for a demonstration and communication vehicle for the model itself, portability of the demonstration or the results to the user, and some idea of how the equipment would be used in operation. It was also desirable to evaluate the suitability of a remote terminal on a time-sharing computer in terms of program size, response time, adequacy of result presentation and costs.

A program based on the student and faculty sectors of the model was designed to operate on the GE 265 computer system, several terminals of which are installed on the campus through arrangements with the Ford Motor Company. In 6:2, a detailed description for using this program is given along with some typical problems that can be analyzed.

The improvement in communication alone has been worthwhile. The computer is a strict disciplinarian, requiring precise definitions and correct descriptions in the model and in the transcription to a program, so that the model-builder is forced to carefully and completely specify the model and its components--he is forced into a thorough understanding of the system being modeled. In some instances, this understanding alone is justification even if the implementation is not completed.

The communication with the user, which was the primary goal, is considerably enhanced when he is requested to use the computer. By sitting at the console, a concrete understanding of what the designer and user each mean is brought about, some hesitancy to use a computer can be overcome, and even with a simple model, additional understanding of the system occurs. The feedback to the model-builder is evidenced when a user, after unsuccessfully trying to solve one of his problems, asks, "How do I get this thing to . . .?" On this simple version, the answer often is that it cannot be done with this program, but the designer has now discovered a need of the user through his question, something that likely would not have happened otherwise.

The fact that the program is portable, requiring a teletype (available through any telephone company) and access to a GE computer system (located in over 35 cities), has been very useful. It has actually been run from three different locations on campus and on six computer systems in five cities.

In terms of the magnitude of the model, the size of this computer system is a serious constraint, but with continued development of computer technology this should be eased considerably. For the size program that can be realistically used, response time is adequate, but presentation of results is a significant limitation, somewhat in format but primarily in the time required.

4:5.2.1 Documentation for MSUSIM

This section contains a description of the equations incorporated in MSUSIM along with the notation and the base data. Typical timing information is also included but depends on how heavily the computer system is loaded by other users. A listing of the program, written in FORTRAN, concludes this section.

The calculations performed are described by the following equations:

1. $s(t)$ = next year's enrollment = S1 =

   $M^{-1}[P\,s(t-1) + a(t)\,n(t) + K_1G_3\,o(t) + K_2h(t)]$, where $M = [I - K_1G_1C - K_1G_2R]$

2. FTE assistantships needed = $g(t) = (G_1\ C + G_2\ R)\ s(t) + G_3o(t)$

3. FTE faculty needed = $f(t) = (F_1C + F_2R)\ s(t)$ (does not include research)

4. Amount of support facilities needed = $e(t) = (E_1\ C + E_2R)\ s(t) + E_3o(t)$

5. Faculty and graduate assistant teaching budget = $[(F_1\ C + F_2R)\,s(t)] \times \hat{f}(t) + [(G_1\ C + G_2R)\ s(t)] \times \hat{g}(t)$ (actually, rows 2 and 4 of G_1 and G_2 are assumed 0)

6. Faculty and graduate assistant research budget =
   $G_3\ o(t)\hat{g}(t) + F_3o(t)\ \hat{f}(t)$ (actually, rows 1 and 3 of G_3 are assumed to be 0)

7. Total budget = BUDT =

$$[(F_1 C + F_2R)\, s(t) + F_3 o(t)]\ \hat{f}(t) + [(G_1C + G_2R)\, s(t) + G_3 o(t)]\ \hat{g}(t) + e(t) \times \hat{e}(t)$$

8. Current credit demand:

$c(t) = Cs(t)$

$r(t) = Rs(t)$

The data required by the program include:

I. F_1, F_2, F_3, G_1, G_2, G_3, E_1, E_2, E_3 which are read in as one large array, T3, stored

$$T3 = \begin{bmatrix} F_1 & F_2 & F_3 \\ G_1 & G_2 & G_3 \\ E_1 & E_2 & E_3 \end{bmatrix}$$

The faculty are not separated according to rank, but rather according to the field and level in which they teach. For the sake of simplicity, faculty research effort also is divided into these same categories (it is not included, however, in computing the teaching budget). A typical entry in an F_1 matrix, then, has units of faculty effort/student credit. The G_1, G_2, and G_3 matrices are arranged in terms of field and type of activity (research or teaching). Rows 1 and 3 of G_1 contain units of graduate assistant class teaching effort/student credit. Rows 2 and 4 of G_3 matrix are units of graduate assistant research effort/unit of outside service. All other rows are 0 (as is all of G_2). The E_1, E_2, and E_3 matrices are fully aggregated (only one row in each), and the entries are units of support facility required/student credit or unit of outside service.

II. C, R matrices: stored in T4, read in as

$$T_4 = \begin{bmatrix} C & 0 \\ R & 0 \\ 0 & 1 \end{bmatrix}$$

III. P matrix, 2 fields, 2 levels.

IV. K_1, K_2 matrices

V. S = the state vector, s(t-1)

VI. O = number of units of outside services

VII. A = % breakdown of new students, giving % that enter each category independent of financial inducement

VIII. H = the number of fellowships, scholarships, etc. available (by field and level)

IX. NSTU = n(t), the number of new students expected to enter the next year. (This number will not necessarily be the actual number of new students the model calls for, but is an approximation.)

X. FH, GH, EH, the unit costs of faculty, grad assistants, and support facilities, broken down as the F, G and E matrices are: (FH = $\hat{f}(t)$, GH = $\hat{g}(t)$, EH = $\hat{e}(t)$)

XI. The numerical values initially assumed by the program are given below:

$$\begin{array}{c|cccc|}
\cline{2-5}
F_1 & .09 & 0 & 0 & 0 \\
 & 0 & .098 & 0 & 0 \\
 & 0 & 0 & .092 & 0 \\
 & 0 & 0 & 0 & .09 \\
\cline{2-5}
 & .05 & 0 & 0 & 0 \\
G_1 & 0 & 0 & 0 & 0 \\
 & 0 & 0 & .05 & 0 \\
 & 0 & 0 & 0 & 0 \\
\cline{2-5}
E_1 & .4 & .25 & .5 & .15 \\
\cline{2-5}
\end{array}
\qquad
\begin{array}{c|cccc|}
\cline{2-5}
F_2 & 1.5 & 0 & 0 & 0 \\
 & 0 & 1.0 & 0 & 0 \\
 & 0 & 0 & 1.4 & 0 \\
 & 0 & 0 & 0 & 1.2 \\
\cline{2-5}
 & 0 & 0 & 0 & 0 \\
G_2 & 0 & 0 & 0 & 0 \\
 & 0 & 0 & 0 & 0 \\
 & 0 & 0 & 0 & 0 \\
\cline{2-5}
E_2 & 0 & .35 & 0 & .15 \\
\cline{2-5}
\end{array}
\qquad
\begin{array}{c|c|}
\cline{2-2}
F_3 & 24 \\
 & 16 \\
 & 60 \\
 & 30 \\
\cline{2-2}
 & 0 \\
G_3 & 60 \\
 & 0 \\
 & 80 \\
\cline{2-2}
E_3 & 200 \\
\cline{2-2}
\end{array}$$

$$\begin{array}{c|cccc|} \hline & 33 & 6 & .5 & .1 \\ C & 2 & 21 & .05 & .1 \\ & 10 & 0 & 42 & 6 \\ & 0 & 9 & 1.5 & 20 \\ \hline & 0 & 0 & 0 & 0 \\ & 0 & 5 & 0 & .1 \\ R & 0 & 0 & 0 & 0 \\ & 0 & 0 & .3 & 6 \\ \hline \end{array}$$

$$F \quad \begin{bmatrix} .45 & 0 & .001 & 0 \\ .02 & .3 & .001 & .02 \\ .1 & 0 & .6 & 0 \\ .01 & .09 & .05 & .4 \end{bmatrix}$$

$$K_1 \quad \begin{bmatrix} .05 & .04 & 0 & 0 \\ .66 & .76 & .05 & .04 \\ 0 & 0 & .06 & .06 \\ .12 & .09 & .75 & .80 \end{bmatrix} \qquad K_2 \quad \begin{bmatrix} .7 & 0 & .075 & 0 \\ .2 & .8 & 0 & 0 \\ 0 & 0 & .6 & 0 \\ 0 & 0 & 0 & .9 \end{bmatrix}$$

$$S = s(t) = \begin{bmatrix} 305 \\ 72 \\ 3000 \\ 484 \end{bmatrix} \qquad \emptyset = \phi(t) = 25$$

$$A = a(t) = \begin{bmatrix} 9.7 \\ .5 \\ 75.5 \\ 6.5 \end{bmatrix}$$

$$H = h(t) \quad \begin{bmatrix} 20 \\ 10 \\ 60 \\ 18 \end{bmatrix} \qquad NSTU = n(t) = 1500$$

$$FH = \hat{f}(t) = \begin{bmatrix} 13000 \\ 14000 \\ 12000 \\ 13000 \end{bmatrix} \qquad GH = \hat{g}(t) = \begin{bmatrix} 4400 \\ 4800 \\ 4400 \\ 4800 \end{bmatrix}$$

$$EH = \hat{e}(t) = 3000$$

Compile program: 35 seconds

Complete year, including print of "you may see," etc., 3 min. 10 sec.

Cycle through one year, no changes - 20 seconds

2 changes, including key - 1 min. 5 seconds

Print for 1 year, "budget only" selected - 1 min. 40 seconds

The next five pages contain a listing of MSUSIM and the initial data.

MSUSIM

```
10* MICHIGAN STATE UNIVERSITY - ENGINEERING RESEARCH - AUGUST 1967
11* EDUCATIONAL INSTITUTION SIMULATION    -   FOWLER, GOODMAN, KEENEY
12 DIMENSION T3(9,9),T4(9,5),K1(4,4),K2(4,4),H1(4,4),H2(4,4),M(4,4),A
13 +(4),H(4),V2(5),V3(9),B1(9,5),T1(4),T2(4),P(4,4),S(4),S1(4),ID(4,4)
14 +,D(4,4),D1(4),F(4),G(4),FH(4),GH(4),C(4),R(4),AN(4),B(4,8),BUD(4)
15 EQUIVALENCE (F(1),V3(1)),(G(1),V3(5)),(E,V3(9)),(S1(1),V2(1)),
16 +(O,V2(5)),(B(1),M(1)),(B(17),ID(1))
17 REAL M,ID,K1,K2
18 PRINT"DEMONSTRATION MODEL"; PRINT" "
19 IX=0; IGI=NO=NS=1; KA=N=4
20 M1=5;M2=8;M3=9;M4=9;M5=5;M6=8;M7=9;M8=9;M9=5
21 BEGIN:READ(1),T3,T4,P,K1,K2,S,O,A,H,NSTU,FH,GH,EH
22 IY=0; IF(IGI)178,178; IF(IX)90
23 BEGIN1: DO 300 I=1,M8; DO 300 J=1,M9; B1(I,J)=0; DO 300 K=1,M4
24 300:B1(I,J)=B1(I,J)+.01*T3(I,K)*T4(K,J)
25 DO 120 I=1,N; DO 120 J=1,N; M(I,J)=0.0; DO 120 K=1,N
26 120:M(I,J)=M(I,J)+K1(I,K)*B1(KA+K,J)
27 DO 200 I=1,N; DO 200 J=1,N; ID(I,J)=0.0; IF(I-J)200,202,200
28 202 ID(I,I)=1.0
29 200: CONTINUE
30 DO 130 I=1,N; DO 130 J=1,N
31 130: M(I,J)=ID(I,J)-M(I,J)
32 DO 140 I=1,4; DO 141 J=1,8
33 141 B(I,J)=B(I,J)/B(I,I)
34 DO 140 L=1,4; IF(L-I) 144,140,144
35 144 DO 143 J=I,8
36 143 B(L,J)=B(L,J)-B(L,I)*B(I,J)
37 140 CONTINUE
38 CALL MV(P,S,S1)
39 DO 150 I=1,N; T2(I)=T3(76+I)*O*0.01
40 T2(I)=T3(76+I)*O*.01
41 150 AN(I)=.01*A(I)*NSTU
42 CALL VA(S1,AN,S1); CALL MV(K2,H ,T1)
43 CALL VA(S1,T1,S1); CALL MV(K1,T2,T1)
44 CALL VA(T1,S1,T1); CALL MV(ID,T1,S1)
45 DO 500 I=1,M8; V3(I)=0; DO 500 J=1,M9
46 500: V3(I)=V3(I)+B1(I,J)*V2(J)
47 DO 800 I=1,N; C(I)=R(I)=0; DO 800 J=1,N; C(I)=C(I)+T4(I,J)*S1(J)
48 800 R(I)=R(I)+T4(N+I,J)*S1(J)
49 IY=IY+1;IF(IGI-1)815,815;PRINT 171,IY;INPUT,IT;IF(IT)79,79
50 171 FORMAT("WANT TO SEE RESULTS FOR YEAR ",I2,"?  (0=NO,1=YES)")
51 815 PRINT,"NO. OF NEW STU",NSTU
52 99 FORMAT(4F10.2)
53 PRINT 101; PRINT"ENROLLMENT THIS YEAR",; PRINT 100,S
54 PRINT"ENROLLMENT NEXT YEAR",; PRINT 100,S1
55 PRINT"MORE INFO? (0=COST TOTALS ONLY,1=ALL BUT RATES,2=ALL,3=NONE)",
56 INPUT,AX;IGI=IGI+2;IF(AX)699,699;IF(2-AX)79;PRINT 117;IF(AX-2)698
57 117 FORMAT(27X,"ENGINEERING",7X,"NON-ENGINEERING"/25X,2("TEACH",
58 +4X,"RESEARCH",3X))
59 PRINT"$/FTE GRAD ASSTSHIP ",; PRINT 100,GH
```

MSUSIM CONTINUED

```
698 PRINT,"FTE ASSTSHIPS NEEDED",; PRINT 100,G; PRINT 101
IF(AX-2)697;PRINT"$/FTE FACULTY MEMBER";PRINT"     TO TEACH          ",
PRINT 100,FH
697 PRINT"FTE FACULTY NEEDED";PRINT"     TO TEACH          ",
DO 685 I=1,N
685 F(I)=F(I)-0*.01*T3(9,I)
PRINT 100,F; PRINT," "
$USE PART2
```

PART2

```
10 IF(AX-2)695;PRINT"$/SUPPORT FACILITY  ",EH
11 695 PRINT," "; PRINT,"AMOUNT OF SUPPORT FACILITIES NEEDED",E
12 PRINT," "; PRINT,"NO. OF OUTSIDE SERVICES",O; PRINT," "
13 699 PRINT"FAC AND GRAD ASST";PRINT"   TEACHING BUDGET     ",
14 BUDT=0; DO 700 I=1,N; BUD(I)=F(I)*FH(I)
15 700 BUDT=BUDT+BUD(I)+G(I)*GH(I)+O*.01*T3(9,I)*FH(I)
16 BUDT=BUDT+E*EH;BUD(1)=BUD(1)+G(1)*GH(1);BUD(3)=BUD(3)+G(3)*GH(3)
17 PRINT 100,BUD;PRINT"   RESEARCH BUDGET:",
18 BUD(1)=O*.01*(T3(9,1)*FH(1)+T3(9,2)*FH(2))+G(2)*GH(2)
19 BUD(2)=O*.01*(T3(9,3)*FH(3)+T3(9,4)*FH(4))+G(4)*GH(4)
20 PRINT"  ENGIN ",BUD(1)," NON-ENGIN ",BUD(2)
21 PRINT" ";PRINT 106,BUDT;PRINT" "
22 100 FORMAT(4F10.0)
23 106 FORMAT("TOTAL BUDGET--FACULTY,GRAD ASST.,AND SUPPORT",F12.2)
24 101 FORMAT(27X,"ENGINEERING",7X,"NON-ENGINEERING"/24X,2("UNDERGRAD"
25 +,4X,"GRAD",3X))
26 103 FORMAT(5X,4F10.5)
27 105 FORMAT(4F10.4)
28 178 PRINT"YOU MAY SEE:ASSTSHIP ATTRACTION TBL-1;SCHLRSHP ATTR TBL-2;"
29 PRINT"CLASS CRED TBL-3;RESEARCH CRED TBL-4;STU TRANSITION TBL-5;"
30 PRINT"PERCENT BRKDWN NEW STU-6; CURRENT CREDIT DEMAND-7;SCHLRSHPS-8;"
31 PRINT"NONE (NO MORE)-9",; IGI=IGI+2
32 110 INPUT,AX; GO TO(10,20,50,60,70,71,72,73,79),AX
33 71 PRINT 99,A;GO TO 110
34 72 PRINT"NO. OF CREDITS--CLASS"; PRINT 100,C
35 PRINT"NO. OF CREDITS--RESEARCH"; PRINT 100,R; GO TO 110
36 73 PRINT"NO. OF SCHOLARSHIPS, ETC."; PRINT 100,H; GO TO 110
37 10 PRINT 105,((K1(I,J),J=1,N),I=1,N);GOTO 110
38 20 PRINT 105,((K2(I,J),J=1,N),I=1,N);GO TO 110
39 50 PRINT 105,((T4(I,J),J=1,N),I=1,N); GO TO 110
40 60 PRINT 105,((T4(I,J),Z=1,N),I=M1,M2);GOTO 110
41 70 PRINT,"STUDENT TRANSITION TABLE"
42 PRINT,"ENGIN UNGR",; PRINT 103,(P(1,I),I=1,N)
43 PRINT,"ENGIN GRAD",; PRINT 103,(P(2,I),I=1,N)
44 PRINT,"N-ENG UNGR",; PRINT 103,(P(3,I),I=1,N)
45 PRINT,"N-ENG GRAD",;PRINT 103,(P(4,I),I=1,N);GOTO110
46 79 IF(IGI)80,80; DO 211 I=1,N
47 211 S(I)=S1(I)
48 80 IYP=IY+1;PRINT"ANY CHANGES FOR YEAR",IYP,"?  (0=NO,1=YES)",
49 INPUT,AC;IF(AC)BEGIN1,BEGIN1;
50 PRINT"WANT KEY FOR CHANGES? (0=NO,1=YES)",; INPUT,AC; IF(AC)91,91
51 PRINT"(NO OF NEW STU-1;OUTSD SERV-2;$/SPPRT FACIL-3;ENROLMNT-4;"
52 PRINT"PERCENT BRKDWN OF NEW STU-5;$/FAC MEM-6;$/GRAD ASST.-7;"
53 PRINT"SCHLRSHPS-8;TRANS TBL-9;CLASS CRED TBL-10;RESEARCH CRED TBL-11;"
54 PRINT,"BACK TO YEAR 0(INITIAL DATA)-12;NO MORE CHANGES-13)"; GO TO 91
55 90 PRINT"MORE CHANGES",
56 91 IX=0;INPUT,AY;IF(12-AY)BEGIN1,190
57 PRINT,"PLEASE TYPE IN THE ENTRIES AFTER '?'"
58 GO TO(222,135,160,109,125,145,155,170,180,180,180,190),AY
59 109 INPUT,S ; GO TO 90;  125 INPUT,A ; GO TO 90
```

PART2 CONTINUED

```
135 INPUT,O ; GO TO 90;  145 INPUT,FH; GO TO 90
155 INPUT,GH; GO TO 90;  160 INPUT,EH; GO TO 90
170 INPUT,H ; GO TO 90;  222 INPUT,NSTU; GO TO 90
190 REWIND 1;IX=-1;GO TO BEGIN
180 PRINT,"TYPE IN A ROW NUMBER AND 4 ENTRIES"
IF(AY-10)1,2,3
1 INPUT,AZ,(P(AZ,I),I=1,4);GOTO 90
2 INPUT,AZ,(T4(AZ,I),I=1,N);GO TO 90
3 INPUT,AZ,(T4(AZ+4,I),I=1,N);GO TO 90
END
SUBROUTINE MV(P1,P2,P3); DIMENSION P1(4,4),P2(4),P3(4)
DO 100 I=1,4; P3(I)=0.0; DO 100 J=1,4
100 P3(I)=P3(I)+P1(I,J)*P2(J)
END
SUBROUTINE VA(P1,P2,P3); DIMENSION P1(4),P2(4),P3(4)
DO 100 I=1,4
100 P3(I)=P1(I)+P2(I)
END
$FILE INDATA
```

INDATA

```
10 .09,3*0,.05,3*0,.4,0,.098,6*0,.25,2*0,.092,3*0,.05,0,.5
11 3*0,.090,4*0,.15,1.5,9*0,1.0,6*0,.35,2*0,1.4,9*0,1.2,4*0,.15,
12 24,16,60,30,0,60,0,80,200
13 33,2,10,6*0,6,21,0,9,0,5,3*0,.5,.05,42,1.5,3*0,.3,0
14 .1,.1,6,20,0,.1,0,6,9*0,1,
15 .45,.02,.1,.01,0,.3,0,.09,.001,.001,.6,.05,0,.02,0,.4,
16 .05,.66,0,.12,.04,.76,0,.09,0,.05,.06,.75,0,.04,.06,.80
17 .7,.2,3*0,.8,2*0,.075,0,.6,4*0,.9,
18 304.72805,72.11710,3000.43200,484.34903
19 25,9.7,.5,75.5,6.5,20,10,60,18,1500
20 13000,14000,12000,13000,4400,4800,4400,4800,3000
```

4:5.3 A Simulation Program--MSUSIM2

The purpose of MSUSIM2 is to provide a useful tool for conducting realistic experiments. To realize this goal it is necessary to develop a language that can be learned and used by administrators themselves. Using MSUSIM as an instructional aid and the User's Manual for MSUSIM2 (4:5.3.1), one person was able to construct an experiment, write and keypunch the simulation program, and obtain a successful run in about 20 hours.

Though the program works mechanically, the development of an adequate data base is difficult, and as a result, experiments using actual data in useful detail have yet to be carried out and evaluated. Such a data base for the College of Engineering has been under construction for the past several months and is just now becoming available (see 4:5.3.3). A series of experiments are planned for the coming year.

The MSUSIM2 User's Manual, 4:5.3.1, is intended as a sufficient guide for understanding and preparing a simulation program in MSUSIM 2 language. Some sample programs are included in D of the manual.

A technical description of MSUSIM2, 4:5.3.2, gives the implementation details, the equations that were used from the theoretical model, and a translation from the notation of the report to that of the program (only a restricted character set is available on the computer). The program listing itself, 4:5.3.4, contains considerable descriptive information, and these two items together should make it possible to understand the program logic.

4:5.3.1 MSUSIM2 User's Manual

The User's Manual is designed and written to be issued as a separate document with enough information to allow a user with little or no computer background to make use of MSUSIM2. The manual is divided into six sections and four appendices.

MSUSIM2

User's Manual

page

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1. Introduction

MSUSIM2 divides the university into up to 8 fields, each of which is an aggregation of one or more departments. It divides students and courses into levels, which may be arbitrary groupings of class codes (for students) and class levels (courses). Faculty are divided into ranks, which may be specified arbitrarily; MSUSIM2 does not require any information about how the divisions are made; it assumes that all data given is grouped properly and consistently.

The user's instructions to MSUSIM2 consist of commands to change selected parameters, commands to project enrollments, demands, or costs, and commands which maintain a file of data for use in the simulations. These commands begin with a call for input, output or modification of parameters, followed by the commands which cause calculations to be performed, commands which employ the data tape, and miscellaneous other commands.

The design of the MSUSIM2 system is such that it may be used for quite a wide variety of purposes. The user may wish to (1) predict future trends in enrollment, (2) calculate the effect of curriculum changes on the teaching faculty required or to determine cost estimates on two alternative courses of action, (3) study the manipulation of enrollment using certain control variables, perhaps to achieve some particular distribution of students among various fields and levels, (4) analyze the current allocation of resources to various types of activities, and (5) study historical changes in certain variables to determine the effects of policy changes.

Because of the flexibility of the MSUSIM2 system, there is a wide variety of types of data which may be supplied to the system, only a portion of which are actually required for any one problem. The user, with the help of this manual, should determine what computational commands will be required for his problem, then supply only the data required for those calculations. For example, if the user wishes to project enrollment for some years into the future but does not wish to use financial aid as a control variable, he need not supply the STUDENT ASSISTANTSHIP or SCHOLARSHIP ATTRACTION or RETENTION tables but should include all student transitions in the STUDENT TRANSITION TABLE. If the user instead is predicting faculty demand five years hence and has already developed a projected enrollment, he need only input that enrollment (HERE IS ENROLLMENT), whatever faculty effort tables he wishes to consider, the DEMAND FOR CREDIT HOURS and RESEARCH GRANTS tables, and compute the required faculty. He may then perform whatever manipulations he desires on the effort parameters to obtain an upper and lower limit for faculty, for example. If faculty salaries are to be considered, then the FACULTY SALARY SCALE must be supplied; and any other costs to be used must also be input. In general, however, only that data to be used need be supplied. If the user wishes to project enrollment or costs for one year under several sets of conditions, he will find the BACK YEAR command useful.

Of course, in many instances the user will already have developed a file of data in a previous use of the MSUSIM2 system. In this case, he does not have to ESTABLISH BACKGROUND and input all of his data but can instead INITIALIZE FROM DATA FILE, which inputs data previously stored on magnetic tape for use by the system. The user may then change any parameters he wishes before beginning his computations.

All of the commands are described in detail in this manual, and their relationships to one another should be clear.

2. Establishment and Initialization of Parameters

ESTABLISH BACKGROUND

This command causes several things to happen. First, all of the system parameters are set to zero. Next, the numbers of fields, levels, and ranks are read, in that order, from the card following the ESTABLISH command. These numbers must be two digits each and must be in the first 6 card columns. For example, the two-card sequence

```
ESTABLISH BACKGROUND
080502
```

would set up the system for 8 fields, 5 levels, and 2 ranks, which is the maximum size allowed.

The system then generates labels for output. These labels are "FIELD 1", "FIELD 2", "LEVEL 1", "RANK 1", etc. The user may later supply his own labels by use of the DESCRIPTION command (see below).

After an ESTABLISH command, the user must specify data before any computations can be done. This may be done with the HERE IS or READ IN commands (see below).

INITIALIZE FROM DATA FILE

A way to introduce a background and data into the system is with the INITIALIZE command. This command must be followed by a file-number-card (see Data File Manipulation, Chapter 5). INITIALIZE causes the data files specified on the file-number-card to be brought into the system. Note that INITIALIZE assumes that all parameters for the system have been included in the file. Any parameters which were not put into the file will be zero after the INITIALIZE. Any data which were in the system before the INITIALIZE will no longer be present. The file number specified for an INITIALIZE must be between 1 and 99.

3. Parameters and Manipulation Commands

In order to describe the parameters used by MSUSIM2, it is helpful to establish the following conventions.

The number of fields under consideration will be written as NF. The number of levels (of students and classes) will be written as NL. The number of faculty ranks will be written as NR. The number of field-level combinations will be denoted NFL, and the number of field-rank combinations, NFR. Thus, since MSUSIM2 allows a maximum of 8 fields, 5 levels, and 2 ranks, the maximum values of NFL and NFR are 40 and 16, respectively (NFL always equals NF times NL; NFR is NF times NR). When data is maintained for each field and level, or each field and rank, it is convenient to regard field 1, level 1 as field-level 1; field 1, level 2 as field-level 2; field 1, level 3 as field-level 3, etc. Thus, if NF were 4, NL were 3, and NR were 2, the field-levels and field-ranks would be numbered as follows:

field	level	field-level
1	1	1
1	2	2
1	3	3
2	1	4
2	2	5
2	3	6
3	1	7
.	.	.
.	.	.
.	.	.
4	3	12

field	rank	field-rank
1	1	1
1	2	2
2	1	3
2	2	4
3	1	5
3	2	6
4	1	7
4	2	8

Data for each parameter is stored in ascending order of field, level, rank, field-level, or field-rank, depending, of course, on the nature of the parameter involved. Each parameter is described in detail below, making use of the conventions already established.

There are several commands which allow the user to reference a single parameter within the system. Each of these commands is followed (on the same card) by a parameter name which specifies the particular parameter which is to be manipulated.

SHOW ME ......

This command causes the system to print the data which is indicated by the parameter name. If the parameter is a table, it will be printed one row at a time. SHOW ME prints up to 8 numbers per line. If the number of elements in a row (i. e., the number of columns) is less than or equal to 8, each row will be printed on a single line. For example, a table with 5 columns and 6 rows will produce 6 lines of output, each line having 5 numbers. EXCEPTION: If a table has only 1 column, the numbers will be printed 8 to a line for as many lines as are needed. For example, a table with 1 column and 12 rows would print 2 lines. Line 1 would contain the first 8 elements of the table (the first 8 rows), and line 2 would contain the remaining 4. If the number of columns is greater than 8, 8 numbers are printed per line for as many lines are as needed to print a row. Each row begins printing on a new line. If, for example, a table has 2 rows and 13 columns, 4 lines will be printed. Line 1 will contain the first 8 elements of row 1, line 2 the last 5 elements from row 1, line 3 the first 8 elements of row 2, and line 4 the last 5 elements of row 2. Of course, if the parameter to be printed is not a table, only one number is printed.

READ IN ....

This command causes the system to input data for the parameter specified by the parameter name. The numbers will be read row-wise, beginning with the card immediately following the READ IN. Numbers are to be punched 8 to a card, each number within a ten column field. Thus the first number goes in card columns 1-10, the second in columns 11-20, etc. EXCEPTION: the READ IN YEAR command must have the year punched cols. 1-4. Each number punched must include a decimal point except for READ IN YEAR which may not have a decimal point (see the example below). Note that there is no correspondence between the number of elements in a row and the number of elements punched on a single card. There must be 8 numbers on each card except the last, which needs to have only enough numbers to fill out the table. If, for example, a table has 3 rows and 7 columns, a READ IN command would require 3 data cards. The first two cards would contain 8 numbers, and the third card only 5 numbers. The first row will be filled with the first 7 numbers from card 1, the second row with the last number from card 1 and the first six from card 2, and the third row with the last 2 numbers from card 2 and the first 5 numbers from card 3. The last 30 columns of card 3 would be ignored. Note that READ IN attempts to fill the entire table from data cards following the command. If there are not enough cards to fill the table, an error will occur.

Of course, if the parameter to be read is not a table, only one number is needed, punched in columns 1-10.

HERE IS ....

This command causes the system to do two things. First, data is read into the parameter (specified by the parameter name) in the same manner as the READ IN. Secondly, the system prints the data in the same manner as the SHOW ME command. Thus the following two command sequences are equivalent:

```
HERE IS RESEARCH GRANTS
1.0        2.5            0.54
```

or

```
READ IN RESEARCH GRANTS
1.0        2.5            0.54
SHOW ME RESEARCH GRANTS
```

INFLATE ....

The INFLATE command is actually a group of commands which allow the user to increase or decrease all or part of any parameter by a proportion specified by the user. For example, if it is desired to give all faculty a raise of 10%, the command would be

```
INFLATE FACULTY SALARY SCALE
ALL
.10
```

The INFLATE command is actually composed of three separate cards: The first contains the word INFLATE followed by the name of the parameter to be increased or decreased, specified exactly as it is in a HERE IS, READ IN, or SHOW ME command. The second card specifies what part of the parameter is to be changed; the possible sub-commands which may be used are

```
ALL
ROWS
COLS
ONLY ROW n
ONLY COL n
ELEMENT m n
```

If ALL is used, the third card must contain the factor to be used in changing the parameter, punched in the first ten columns of the card. If the parameter is a table, each entry in the table will be increased by the proportion specified. A negative value, of course, will cause a decrease.

Example:

INFLATE FACULTY SALARY SCALE
ALL
. 10

will give all faculty a 10% raise

INFLATE STUDENT TRANSITION TABLE
ALL
-. 20

will cause each entry in the transition table to be lowered by 20%.

If ROWS is used as the sub-command, the third card must contain one entry for each row in the table (parameter) to be inflated. For example, if the student transition table is to be inflated, and if there are 3 fields and 2 levels, then the student transition table has 6 rows and 6 columns, and the third card must have 6 entries, each in 10 columns of the card. An illustration is:

INFLATE STUDENT TRANSITION TABLE
ROWS

$$\underbrace{.10}_{\text{10 col's}} \quad \underbrace{.08}_{\text{10 col's}} \quad \underbrace{.06}_{\text{10 col's}} \quad \underbrace{.08}_{\text{10 col's}} \quad \underbrace{.10}_{\text{10 col's}} \quad \underbrace{.09}_{\text{10 col's}}$$

This command would inflate all entries in the first row by 10%, in the second row by 8%, in the third by 6%, etc. Any fields left blank are treated as 0 by the system (i. e., the corresponding row is unchanged).

If COLS is used as the sub-command, the third card is prepared as for ROWS, but the command inflates the first column by the first value, the second column by the second value, etc.

If ONLY ROW nn is used, the third card must contain only one entry, in the first 10 columns, and n must be a two-digit number. The user must be certain that the row number specified is not greater than the number of rows in the table he is altering.

Example:

```
INFLATE STUDENT TRANSITION TABLE
ONLY ROW 03
.15
```

This command inflates row 3 of the table by 15%.

If ONLY COL nn is used, the third card is prepared as in ONLY ROW nn. Column n is altered, instead of row n.

Example:

```
INFLATE STUDENT TRANSITION TABLE
ONLY COL 02
-.10
```

This command reduces column 2 by 10%.

If ELEMENT mm nn is used, the third card contains one entry in the first 10 columns. Both m and n must be 2-digit numbers, specifying the row and column, respectively, of the entry to be inflated.

Example:

```
INFLATE DEMAND FOR CREDIT HOURS
ELEMENT 02 03
.12
```

This command inflates the entry in row 2, column 3 of the DEMAND FOR CREDIT HOURS table by 12%.

ENROLLMENT

For the purposes of MSUSIM2, enrollment means the number of students in each field-level under consideration in a given year. The enrollment is stored as a table with one column, and with one row for each field-level. Thus, for example, if NF = 4, NL = 3, then the input cards

```
HERE IS ENROLLMENT
250.    230.    55.    600.    350.    125.    170.    150.
 60.    150.    88.     35.
```

would indicate to MSUSIM2 that the enrollment to be considered is 250 field-level 1 students, 230 field-level 2 students, etc., finally up to 35 field-level 12 students. After this command is executed, the fourth row of the enrollment table will contain the number 600, for example.

The enrollment table always contains the last enrollment input or computed by a COMPUTE ENROLLMENT command. (Of course, INFLATE ENROLLMENT also alters the enrollment table.)

NUMBER OF TOTAL NEW STUDENTS

The number of total new students is the number of students entering the university in the year under consideration who were not in the university the previous year. Both students attracted by financial aid and those who enter independent of aid are included. No division into fields and levels is done at this stage; the proportion of the total new students who enter each field-level is stored as the PERCENT BREAKDOWN OF TOTAL NEW STUDENTS table, described next. NUMBER OF TOTAL NEW STUDENTS is used only by the COMPUTE ENROLLMENT

FROM TOTAL NEW STUDENTS command; if this command is not used, NUMBER OF TOTAL NEW STUDENTS need not be supplied.

PERCENT BREAKDOWN OF TOTAL NEW STUDENTS

This table is a single column which contains one row (a single entry) for each field-level category. The entry in row J is just the proportion of total new students (for the year under consideration) who enter field-level J. Thus, for example, if 10 percent of all new students enter field-level 3, then .10 should be the third entry of the table. This parameter is necessary only when the COMPUTE ENROLLMENT FROM TOTAL NEW STUDENTS command is to be used.

NUMBER OF NEW STUDENTS AID INDEPENDENT

The number of new students, aid-independent, is the number of students entering the university in the year under consideration who were not in the university the previous year but who would have entered the university even if financial aid were not offered them. This number includes students who receive aid but would attend even if they did not have aid together with all students who do not receive aid. This parameter is used, in conjunction with the PERCENT BREAKDOWN OF NEW STUDENTS AID INDEPENDENT, whenever the COMPUTE ENROLLMENT FROM NEW STUDENTS AID INDEPENDENT command is executed.

STUDENT TRANSITION TABLE

This table describes the movement of students already within the university among the various field-levels from one year to the next, independent of financial aid. The table has NFL rows and NFL columns, i.e., a row and column for each field-level. The information recorded in the entry of the i^{th} row and j^{th} column is the proportion of students in field-level j in year t-1 who are in field-level i in year t. For example, if the entry in row 4 column 3 is .50, this indicates that 50% of the students who were in field-level 3 in year t-1 are in field-level 4 in year t and would be in field-level 4 whether they were offered financial aid or not. (Note - if the user wishes to ignore the effects of financial aid on enrollment, he may include all transitions, whether induced by financial aid or not, in the transition table. He must then make certain that the scholarship and assistantship attraction and retention tables described below are all 0.) The STUDENT TRANSITION TABLE is used when either COMPUTE ENROLLMENT FROM NEW STUDENTS AID INDEPENDENT or COMPUTE ENROLLMENT FROM TOTAL NEW STUDENTS is executed. Of course, when the user is projecting a future enrollment, the transition table is only an estimate of the transitions to be expected, and the user may wish to use the transition table for the most recent year, an average over several previous years, or some other estimate of the transitions to be expected.

STUDENT ASSISTANTSHIP ATTRACTION TABLE

This table specifies the effect of financial aid in the form of teaching and research assistantships in causing students to enter or remain at the university in a given field-level. There are NFL rows in this table (and only one column). The i^{th} row in the table is the number of students who will be in field-level i in year t who would not be in the university if an assistantship were not offered in field-level i, per assistantship to be offered for year t in field-level i. (Clearly, the attraction of students outside field-level i by an assistantship in field-level i is assumed to be small and is therefore ignored.) For example, if each assistantship in field-level 3 attracted .7 students, then the third row should contain .7. Of course, assistantships are normally offered only in graduate levels, so all undergraduate field-levels will usually be 0.

STUDENT SCHOLARSHIP ATTRACTION TABLE

This table is identical to the STUDENT ASSISTANTSHIP ATTRACTION TABLE, except that it deals with students attracted by scholarships, fellowships, and traineeships, rather than by assistantships. (As undergraduates receive scholarships, the undergraduate levels will not in general be 0, as they were in the assistantship table.) There remains for the user the problem of deciding how many scholarships are "available" in each field-level, since some do not require that the recipient be a student in a particular field-level--it may be that the user wishes to recognize only those scholarships which specify a field or field-level of recipient, or the user may instead "assign" scholarships to field-levels in proportion to their enrollments. Any such scheme is acceptable so long as it is applied consistently within any single set of data, i.e., for those parameters specifying numbers "independent of financial aid," only those types of aid considered in the STUDENT SCHOLARSHIP ATTRACTION TABLE and the STUDENT ASSISTANTSHIP ATTRACTION TABLE should be considered as financial aid.

STUDENT ASSISTANTSHIP RETENTION TABLE

This table describes the effect of assistantships in causing students to remain in the university. It is a square table, with NFL rows and NFL columns. The entry in row i, column j is the number of students in field-level i in year t-1 who are induced not to depart from the university by an assistantship offered for year t in field-level j. For example, if each assistantship offered in field-level 5 for year t causes .8 students from field-level 4 in year t-1 not to depart from the university, then the entry in row 4, column 5 should be .8. (It is to be expected that many seniors and graduate students will be induced not to leave by assistantships and that rows corresponding to other levels (and columns corresponding to all undergraduate levels) will be 0 or nearly 0.)

STUDENT SCHOLARSHIP RETENTION TABLE

This table is identical to the STUDENT ASSISTANTSHIP RETENTION TABLE except that it deals with students induced not to depart by scholarships rather than by assistantships.

DEMAND FOR TEACHING ASSISTANTS

This table contains information about the number of graduate teaching assistants required for each student credit hour taught. The table has NFL rows and NFL columns. Each row represents a field-level of graduate assistants, i.e., the level of student and field of the assistantship; since undergraduates are not teaching assistants, rows corresponding to undergraduate levels will be 0. Each column represents a field-level of student credit hours. Thus the entry in row i, column j is the number of teaching assistants of field-level i required to teach one student credit hour of a class in field-level j. For example, if row 5 column 2 contains .006 and if field-level 5 represents graduate students in field 1, this indicates that .006 graduate teaching assistants in field 1 are required for each student credit hour taken at level 2 in field 1.

It may be convenient to measure graduate assistantships in units of half-time equivalents rather than in head count; this may be done, but it must be done consistently in the STUDENT ASSISTANTSHIP ATTRACTION and RETENTION tables also. (If this table is not supplied, teaching assistants cannot be computed, and the effect of teaching assistantships in attracting and retaining students cannot be computed.)

DEMAND FOR RESEARCH ASSISTANTS

This table contains information about the number of research assistants required per $1000 of research grants in a given field. The table has NFL rows and NF columns. The entry in row i, column j is the number of research assistants of field-level i required per $1000 of research grants in field j. As in the case with teaching assistants, the user may wish to define a full-time or half-time research assistant to use instead of a head count.

RESEARCH GRANTS

This table contains the amount of research grants held in each field. There are NF rows, only one column. The entry in row i is the number of thousands of dollars of research grants in field i for the year under consideration. For example, if field 3 has $72,500 in grants for the year under consideration, the third entry in the table should be 72.5. (The user may choose to consider research funds from various sources, of course, so long as he is consistent in using funds considered in determining the EFFORT FOR RESEARCH and the DEMAND FOR RESEARCH ASSISTANTS tables.)

STUDENT GRADUATION PERCENT TABLE

This table contains the proportion of students of each field and level who graduate during the year under consideration. The table has NFL rows and a single column. Row i contains the proportion of field-level i students who graduate in a given year. Of course, only those rows corresponding to senior and graduate levels will contain non-zero entries.

DEMAND FOR CREDIT HOURS

This table contains the credit-hour requirements of all students. The table has NFL rows and NFL columns; the entry in row i, column j is the number of student credit hours of courses at field-level i that are required per student at field-level j. Thus, if row 3, column 2 contains 11.6, it indicates that each student at level 2 required 11.6 student credits at field-level 3 (i.e., if field-level 2 is sophomore-level mathematics and field-level 3 is junior-level mathematics, the 11.6 represents 11.6 credits of junior-level math courses taken by the average sophomore-level mathematics major). While the user might ordinarily wish to count credits demanded over a period of an academic year, he may instead use credits for an "average quarter"; all that is required is that the same scheme be used consistently, for example, in determining the effort for undergraduate and graduate instruction tables.

NUMBER OF SCHOLARSHIPS

This table specifies for each field-level the number of scholarships, fellowships and traineeships to be offered for students entering or remaining in that field-level. Thus the table has NFR rows and a single column. The units of scholarships must be chosen by the user, of course; he may wish to define a standard scholarship or some such quantity in terms of which to express scholarships of different values. He should, of course, use the same units in calculating the STUDENT SCHOLARSHIP ATTRACTION TABLE and the STUDENT SCHOLARSHIP RETENTION TABLE.

The following twelve tables represent the various activities faculty may devote time to. The amount of time devoted to the first six of these activities is assumed to be a direct function of some other variable. The entries in these six tables, therefore, have the units "FTEs per some quantity." The last six of these tables do not depend on any clear cut demand. The entries in these tables, therefore, have the units "fraction of FTEs."

These tables are all required by the commands: COMPUTE FACULTY; COMPUTE FACULTY COSTS; and COMPUTE TOTAL COSTS.

EFFORT FOR UNDERGRADUATE INSTRUCTION

This table gives the amount of effort per credit spent by faculty of each field and rank teaching undergraduate courses of each field and level. The number of FTEs spent by the faculty of a given field and rank teaching undergraduate courses of a given field and level is divided by the total number of undergraduate credits taken in the given field and level from the faculty of the given field and rank.

This table has NFR rows and NFL columns. The entry in row i column j is the number of FTEs per student credit spent by the faculty of field-rank i teaching undergraduate courses for students in field-level j. For example, if the faculty of field-rank 3 spend 0.35 FTEs teaching undergraduate courses of field-level 8 and if these courses represented 100 student credits, then 0.0035 ($\frac{.35}{100}$) would be entered in row 3, column 8 of the table.

EFFORT FOR GRADUATE INSTRUCTION

This table is equivalent to the EFFORT FOR UNDERGRADUATE INSTRUCTION table except that it gives the number of FTEs spent by the faculty of each field and rank teaching graduate courses in each field and level.

This table has NFR rows and NFL columns. As an example of an entry, suppose that the faculty of field-rank 5 spent 0.25 FTEs teaching graduate courses in field-level 15 and suppose that these courses totaled 50 student credits, then 0.005 ($\frac{0.25}{50}$) would be entered in row 5, column 15 of the table.

EFFORT FOR UNDERGRADUATE ADVISING

This table gives the effort per student spent by faculty of each field and rank performing undergraduate advising for students of each field and level. The number of FTEs spent by faculty of a given field and rank performing undergraduate advising for students of a given field and level is divided by the number of students in that field and level.

This table has NFR rows and NFL columns. The entry in row i, column j is the number of FTEs per student spent by faculty of field-rank i performing undergraduate advising for students of field-level j. For example, if faculty of field-rank 3 spend 0.1 FTEs advising students of field-level 20 and if there are 100 students in field-level 20, then 0.001 ($\frac{0.1}{100}$) would be entered in row 3, column 20 of the table.

EFFORT FOR GRADUATE ADVISING

This table is equivalent to the EFFORT FOR UNDERGRADUATE ADVISING table except that it gives the effort per student spent by faculty of each field and rank performing graduate advising for students of each field and level.

This table has NFR rows and NFL columns. As an example of an entry, suppose faculty of field-rank 2 spent 0.05 FTEs performing graduate advising for students of field-level 5 and that there are twenty-five students in field-level 5, then 0.002 ($\frac{0.05}{25}$) would be entered in row 2, column 5 of the table.

EFFORT FOR THESIS SUPERVISION

This table is equivalent to the EFFORT FOR UNDERGRADUATE ADVISING table except that it gives the effort per student spent by faculty of each field and rank performing thesis supervision for students of each field and level.

This table has NFR rows and NFL columns. As an example of an entry, suppose that faculty of field-rank 10 spent 0.04 FTEs performing thesis supervision for students in field-level 7 and that there are twenty students in field-level 7, then 0.002 ($\frac{0.04}{20}$) would be entered in row 10, column 7 of the table. Since undergraduates do not in general write theses, the columns corresponding to undergraduate levels will normally be 0.

EFFORT FOR RESEARCH

This table contains the effort spent by faculty of each field-rank doing research, per $1000 of research grants in each field. The number of FTEs spent by faculty of a given field and rank performing research in in a given field is divided by the total number of $1000 of outside research grants received for research in that field.

This table has NFR rows and NF columns. The entry in row i, column j is the number of FTEs per $1000 outside research grants held by faculty of field-rank i doing research in field j. For example, if faculty of field-rank 9 spent 4 FTEs performing research in field 5 and field 5 has received a total of $200, 000 in outside research grants, then 0. 02 (4/200) would be entered in row 9 column 5 of the table.

In general, of course, most faculty research effort in a given field will be provided by faculty of the same field, so many entries will be zero.

Each of the following six tables relates faculty effort for some activity to the sum of all faculty effort for the six activities above. That is, for example, a typical entry in the EFFORT FOR SEMINARS AND MEETINGS table is the ratio of the effort a faculty member of a given field and rank spends on seminars and meetings to what he spends on teaching, advising, and research taken together (i. e., on the activities described by EFFORT FOR UNDERGRADUATE and GRADUATE INSTRUCTION, FOR UNDERGRADUATE and GRADUATE ADVISING, FOR THESIS SUPERVISION, and FOR RESEARCH--see above).

EFFORT FOR COMMITTEE WORK

This table has NFR rows, each a single entry. The entry in row j is the ratio of the average effort a faculty member in field-rank j spends on committee work to the effort he spends on teaching, advising, and research (as discussed above).

EFFORT FOR UNDERGRADUATE COURSE DEVELOPMENT

This table has NFR rows, each containing a single entry. The entry in row j is the ratio of the average effort a faculty member in field-rank j spends on undergraduate course development to the effort he spends on teaching, advising, and research (as discussed above).

EFFORT FOR GRADUATE COURSE DEVELOPMENT

This table is identical to the EFFORT FOR UNDERGRADUATE COURSE DEVELOPMENT table, except that the effort under consideration is that for graduate course development.

EFFORT FOR PUBLIC SERVICE

This table is identical to the EFFORT FOR UNDERGRADUATE COURSE DEVELOPMENT table, except that the effort under consideration is that for public service.

EFFORT FOR SEMINARS AND MEETINGS

This table is identical to the EFFORT FOR UNDERGRADUATE COURSE DEVELOPMENT table, except that the effort for seminars and meetings (excluding that effort attributable to one of the other activities such as research, etc.) is to be considered instead of the effort for undergraduate course development.

EFFORT FOR ADMINISTRATION

This table is identical to the EFFORT FOR UNDERGRADUATE COURSE DEVELOPMENT table, except that the effort to be considered is that spent on administration (excluding that effort attributable to one of the other activities, such as research, etc.).

The following twelve tables are very similar. A detailed description will be given of the first and the minor differences will be pointed out for those remaining.

FRACTION COST OF SECRETARIES FOR UNDERGRADS

This is a table with NF rows and one column. It contains information on what proportion of the total costs of secretaries for each field is devoted to work directly related to undergraduates. For example, if the secretaries in field 3 devoted 20% of their time to undergraduate related work, the third element of the table should contain a .20. This and the other tables like it are used only by a COMPUTE TOTAL COSTS command and need not be supplied if the user is not interested in the overhead or total costs.

FRACTION COST OF SECRETARIES FOR GRADS

This table is exactly like the above except that it provides information on proportions of time devoted to work directly related to graduate students.

FRACTION COST OF SECRETARIES FOR THESIS AND RESEARCH

This table is exactly the same as the first except that it supplies information on proportions of work related to thesis and research.

FRACTION COST OF EQUIPMENT FOR UNDERGRADS

This table differs from the first in that it contains the proportions of the total costs of equipment of each field that is related to undergraduates.

FRACTION COST OF EQUIPMENT FOR GRADS

This table is the same as the above except that it applies to equipment costs related to the graduate program.

FRACTION COST OF EQUIPMENT FOR THESIS AND RESEARCH

This table is the same as the above except that it refers to equipment costs related to thesis and research.

FRACTION COST OF SUPPLIES AND SERVICES FOR UNDERGRADS

This table is the same as the first except that it applies to cost of supplies and services related to undergraduate studies.

FRACTION COST OF SUPPLIES AND SERVICES FOR GRADS

This table is the same as the above except that it applies to graduate studies.

FRACTION COST OF SUPPLIES AND SERVICES FOR THESIS AND RESEARCH

This table is the same as the above except that it applies to thesis and research.

FRACTION COST OF LABOR FOR UNDERGRADS

This table is the same as the first except that it contains the proportions of costs of labor related to undergraduate studies in each field. Labor includes all types of labor except that of secretaries and graduate assistants.

FRACTION COST OF LABOR FOR GRADS

This table is the same as the above except that it applies to graduate studies.

FRACTION COST OF LABOR FOR THESIS AND RESEARCH

This table is the same as the above except that it applies to thesis and research.

The costs not accounted for by the preceding 12 tables will be treated as cost of other activities by the program. For example, if the secretaries in field 2 devote 20% of their time to undergraduate related work, 20% of their time to graduate related work, and 30% of their time to thesis and research related work, the program will assume that 30% of their time is devoted to other activities.

FACULTY SALARY SCALE

This table contains salary information for each field and rank of faculty. There are NFR rows each of which contains a single entry. The entry in row j is the average salary of a faculty member of field-rank j. This table is used when the COMPUTE FACULTY COSTS or COMPUTE TOTAL COSTS commands are executed.

ASSISTANTSHIP SALARY SCALE

This table contains salary information for graduate assistants. The table has NF rows and one column. The entry in row j is the average salary of a graduate assistant in field j. (As should be clear, no differentiation is made as to the level of the graduate assistant -- an overall average figure is used.)

4. Computational and Display Commands

COMPUTE ENROLLMENT FROM NEW STUDENTS AID INDEPENDENT

This command causes a projection from year t-1 to year t of the number of students in each field and level. The program calculates the number of students attracted by financial aid, using a preliminary estimate of the number of teaching assistants required for the next year, together with the number of scholarships offered and the number of research assistants required. It adds these students to the students entering independent of aid to obtain the total number of new students entering the university in year t, then calculates the number of students expected to carry over, finally obtaining the estimate of the enrollment for year t. Also calculated are the number of students expected to leave the university during or after year t-1, the number expected to graduate in year t-1, and the projection of student credit hours in each field and level which will be required for year t. The year is finally advanced by 1, and what was formerly regarded as year t will be regarded as year t-1 when enrollment is projected again. It is the projection of enrollment which causes this advance of the year under consideration, as the variable assumed best to describe the "state" of the university is the enrollment in each field and level, and when it is projected ahead a year, the university is essentially "in" that new year. All calculations performed by this command may be printed by using the DISPLAY ENROLLMENT command.

COMPUTE ENROLLMENT FROM TOTAL NEW STUDENTS

This command causes a projection from year t-1 to year t of the number of students in each field and level and advances the year by 1.

The program calculates the expected enrollment, calculates how many of the new students were attracted by aid, then subtracts to determine how many students entered independent of financial aid. Also calculated are the number of students expected to leave the university during or after year t-1 and the number expected to graduate in year t-1. The results of all of these calculations may be printed by the DISPLAY ENROLLMENT command.

COMPUTE FACULTY

This command causes calculation of the number of full-time equivalent faculty and half-time graduate assistants which will be required to meet the demands placed upon the university by the student sector and by external demands, such as research grants, during the year under consideration (year t). It utilizes the student enrollment most recently computed or input, together with the demand for credit hours, the amount of research grants, and the faculty effort parameters, to calculate the total number of full-time equivalent faculty of each field and each rank which are required to satisfy the demands. Also calculated are the numbers of graduate assistants required for teaching and research in each field, assuming that each assistant is appointed half-time. The results of these calculations may be printed via the DISPLAY FACULTY command.

COMPUTE FACULTY COSTS

This command causes computation of the direct costs for faculty of each field and rank for the undergraduate program, for the graduate program, for thesis direction and research work, and for other activities. Included as "other activities" are administration, public service, seminars and meetings, and committee work. This command also causes the calculations of the COMPUTE FACULTY command to be done, so COMPUTE FACULTY need not be used first; instead the command sequence should be COMPUTE FACULTY COSTS, DISPLAY FACULTY, and DISPLAY FACULTY COSTS. Graduate assistants are not included in the costs calculated by this command. In addition to the data required to COMPUTE FACULTY, this command requires the faculty salary scale.

COMPUTE TOTAL COSTS

This command causes computation of overhead costs by field including secretarial, supplies and services, equipment, and labor costs. Each of these costs is distributed among the undergraduate, graduate, and thesis and research programs of each field according to "fraction costs" data, with the proportion of costs not attributable to those programs assigned as "cost of other activities." Costs of graduate research assistants and of graduate teaching assistants are computed. Total costs by field (including faculty, overhead, and graduate assistants) are computed for the undergraduate program, the graduate program, the thesis and research program, and other activities, and the sum of the four is computed (total costs). In addition to the fraction cost data, this command utilizes the assistantship salary scale and the secretarial, labor, equipment, and supplies and services costs. The calculations performed include those of the COMPUTE FACULTY COSTS and COMPUTE FACULTY commands, so if total costs are to be calculated, neither of the former commands need be used -- instead the command sequence might be COMPUTE TOTAL COSTS, DISPLAY FACULTY, DISPLAY FACULTY COSTS, and DISPLAY TOTAL COSTS (however, it is not necessary to display either faculty or faculty costs unless desired).

DISPLAY ENROLLMENT

This command prints the information computed by the commands COMPUTE ENROLLMENT FROM TOTAL NEW STUDENTS or COMPUTE ENROLLMENT FROM NEW STUDENTS AID INDEPENDENT.

DISPLAY FACULTY

This command prints the information computed by the COMPUTE FACULTY command. It may also be used after the commands COMPUTE FACULTY COSTS or COMPUTE TOTAL COSTS have been executed.

DISPLAY FACULTY COSTS

This command prints the information computed by the COMPUTE FACULTY COSTS command. It may also be used after COMPUTE TOTAL COSTS has been executed.

DISPLAY TOTAL COSTS

This command prints the information computed by the COMPUTE TOTAL COSTS command.

BACK YEAR

This command causes the year to be decremented by one and the enrollment to be replaced by the preceding year's enrollment. The purpose of this instruction is to allow the user to project the enrollment under varying conditions. BACK YEAR should not follow a READ IN YEAR, HERE IS YEAR, INITIALIZE, HERE IS ENROLLMENT, INFLATE ENROLLMENT, READ IN ENROLLMENT, or BACK YEAR without first using a COMPUTE ENROLLMENT or an error flag will be given. It is the user's responsibility to restore any changes he has made to variables other than the enrollment. BACK YEAR simply replaces the projected enrollment with the enrollment of the year prior to the projection and decrements of the year. No other changes are made by BACK YEAR.

5. Data File Manipulation

Data for MSUSIM2 may be stored on magnetic tape as permanent or semi-permanent files. (See B for details on how to set up the tape configuration for your computer system.) MSUSIM2 allows up to 99 files on any one reel of tape. Each file can contain up to one complete set of parameters for the system. For example, a data file could contain: data for the various departments in a college in a given year; data for several of the colleges in a university in a given year; a projection ahead to a given year; or possibly data from a past year for analysis purposes.

There are three basic commands for manipulating data files. The card following each of these command cards must be a file-number-card. This card must have a 2-digit file number in columns one and two. This file number tells the system which file is to be manipulated.

AUGMENT DATA FILE

The AUGMENT command causes a new file to be put on the tape. The data which goes onto the tape contains all of the parameters which the system has at the time when the command is given. (This data could have been introduced to the system by an INITIALIZE, or by an ESTABLISH followed by a set of HERE IS or READ IN commands.) After the AUGMENT has been done, the parameters remain intact within the system (i.e., no data are destroyed).

The file number specified for the AUGMENT must be between 0 and 99. If the file number is zero, the system assigns the first available number to the file. In this way the user may AUGMENT the tape without knowing what files are already on it. Note, however, that to reference this file, the user must check his program printout to find its assigned number. Thus, it would be impossible to reference that file again in the same run.

If the specified file number is between 1 and 99, the file is assigned the specified number unless a file with that number already exists. In this case the system assigns the next available number to the file, and a message is printed giving the number which was actually assigned. An example is:

```
AUGMENT DATA FILE
02
```

```
THE AUGMENT YOU HAVE REQUESTED CANNOT BE MADE.  FILE 2
ALREADY EXISTS.  FOR THIS RUN ONLY, REFERENCES TO FILE 2 WILL
BE INTERPRETED AS REFERENCES TO FILE 4.  IN FUTURE RUNS,
HOWEVER, YOU MUST CORRECTLY REFERENCE THE DATA SET AS
FILE 4.
```

In this case the user wanted to add a file 2 to the tape, but since there already was a file number 2 on the tape, the system assigned the file to number 4. Then, for the rest of the run, the system remembers that what the user calls file 2 is actually file 4. For example, the command

```
UPDATE DATA FILE
02
```

will cause file 4 to be updated as described below.

This relationship between file numbers is called "equivalence"; in this example file 2 is "equivalent" to file 4. The user may have up to five equivalenced files at any one time. Recall that at the end of a run all equivalences are lost.

Following the file-number-card for the AUGMENT command, there must be five cards. The information on these cards will be included with the file information on the tape. These cards may contain a name or description for the file, or they may be blank, but all five cards must be there.

UPDATE DATA FILE

This command causes the data of an already-existing file to be replaced by the data which is currently in the system. The file to be UPDATED is indicated on a file-number-card as described above. The file number must be between 1 and 99. Note that an UPDATE is a total replacement; none of the old data is saved. If the user wishes to change only a small part of a file, one possible command sequence is:

```
INITIALIZE FROM DATA FILE
17
HERE IS
.
.
.
READ IN
.
.
.
INFLATE
.
.
.
UPDATE DATA FILE
17
```

This command sequence causes the following things to happen:

(1) The data from file 17 is brought into the system.

(2) The data is altered within the system using any legal user commands (the examples shown are HERE IS, READ IN, and INFLATE).

(3) The altered data from the system replaces the old data in file 17.

DELETE FROM DATA TAPE

This command causes a file to drop from the tape. All of the data from the file is lost. The file to be DELETED is specified on a file-number-card, and must be between 1 and 99.

There are also three auxiliary commands for manipulating the data tape as a whole. File-number-cards are not allowed after these commands.

LIST DATA TAPE

This command causes the system to print a complete listing of the files currently on the tape. For each file the system prints the file number, the data when the file was augmented or updated the last time, and the five-card description of the file.

Q25QCOPY

This command causes the system to write a complete copy of the current data tape. This copy can be used as a safety backup, or the two tapes can be used interchangeably.

Q25QINIT

This is a special command, and should be used very carefully. When a fresh tape is to be used for a data tape, Q25QINIT causes the system to write certain essential information on the tape. Q25QINIT must be used before the first AUGMENT command is done on the tape, or an unpredictable error will occur. WARNING: If the command Q25QINIT is given when a tape already has data files on it, all of the files will be destroyed and this data lost!!

6. Miscellaneous Commands

NO LIST

This command prevents all commands following it from being listed in the program output. The main purpose of this command is to allow the user to have program output without commands interspaced in it once he has established a working set of commands. However, a HERE IS or SHOW ME command will cause the referenced variable to be printed. It is the user's responsibility to provide labels for variables referred to by a HERE IS or SHOW ME command while in NO LIST mode. The simultaneous use of DEBUG and NO LIST is not recommended.

HEADING . . .

This command allows the user to write headings for anything that is printed in the program output. The heading can be punched in any of the columns after column eight of the HEADING card. If more than one card is required, the word HEADING should appear on each card starting in the first column. The heading will appear in the output with the word HEADING when in LIST mode and without the word HEADING when in NO LIST mode.

DESCRIPTION . . .

This command allows the user to provide labels for the fields of study, levels of students, and ranks of faculty. The user should specify which description he is providing by completing the DESCRIPTION card with either OF FIELDS, OF LEVELS, or OF RANKS. On the next card after the DESCRIPTION card the user should punch the labels he wishes to provide, starting in column one of the card. Each label should be exactly eight characters long. If the label is less than eight characters, the user should leave blanks to fill the remaining spaces. In no case should the label be more than eight characters.

Examples

```
DESCRIPTION OF FIELDS
CEM∧∧∧∧∧HPR∧∧∧∧∧SOC SCI∧

DESCRIPTION OF LEVELS
FROSH∧∧∧SOPH∧∧∧∧JUNIOR∧∧SENIOR∧∧

DESCRIPTION OF RANKS
HIGHRANKLOWRANK∧
```

DEBUG

This command prevents the execution of all commands following it that involve computation, display, or tape handling. The purpose of this command is to run a set of instructions and discover any errors that it may contain without the expense of meaningless computation. INITIALIZE, ESTABLISH BACKGROUND, HERE IS, READ IN, and SHOW ME are the only instructions executed while in DEBUG mode. Since the AUGMENT DATA FILE command is not executed in DEBUG mode, care should be taken not to initialize with a file created by an AUGMENT in DEBUG mode because the file will not exist. Care should also be taken to be sure that the data input with a HERE IS or READ IN command, following an ESTABLISH BACKGROUND, is compatible with the number of fields, levels and ranks given, or the program may be terminated.

LIST COMMANDS

This command causes all commands to be listed again after listing has been prevented by a NO LIST command. LIST COMMANDS need only be used after a NO LIST, but redundant use of it will be treated as a "do nothing" command.

COMMENT

This command allows the user to insert comments throughout a set of commands. The comment can be punched in any of the columns after column eight of the COMMENT card. If a comment requires more than one card, the word COMMENT should appear in the first seven columns of each card. The word COMMENT is printed with the comment in LIST mode and neither the word COMMENT nor the comment is printed in NO LIST mode.

RECOVER

Whenever MSUSIM2 is operating in DEBUG mode, RECOVER is a do-nothing command. Otherwise, when an error occurs, the system prints an error message and scans through the remaining commands (without executing them) until it reads a RECOVER command. RECOVER indicates to the system that it is safe to continue executing even though an error has previously occurred. The RECOVER command should be used sparingly to avoid wasteful computation and possible loss of data. For example, consider the following command sequence:

```
.
.
.
.
ENITIALIZE FROM DATA FILE
17
RECOVER
INFLATE STUDENT TRANSITION TABLE
ALL
.05
COMPUTE ENROLLMENT FROM TOTAL NEW STUDENTS
```

```
RECOVER
UPDATE DATA FILE
17
DISPLAY ENROLLMENT
.
.
.
.
```

The mis-spelled INITIALIZE will not be recognized, causing an error. The data from file 17 will not be read in, and the system will begin to scan. A RECOVER command is found almost immediately, and the system continues execution with the INFLATE command. Note, however, that the INITIALIZE was not executed, so that the data within the system is whatever was left over from preceding commands. Thus, when the UPDATE is performed, the data in file 17 will be lost. Always remember: use RECOVER commands sparingly!! (As a rule of thumb, RECOVER should be used only when the commands which follow the RECOVER card should be properly executed even before any of the commands prior to the RECOVER card had been executed.)

A

KEYPUNCHING INSTRUCTIONS

All commands begin in column 1 of a card. If the command consists of more than one word, each word must be separated by exactly 1 space. All commands must be spelled correctly. Any cards which are not commands have been described above. Recall that a file-number-card must have a 2-digit file number in columns 1 and 2. Data for HERE IS or READ IN commands (except for YEAR) must include a decimal point and must be punched 8 numbers to a card in 10-column fields (i.e., first number in columns 1-10, second number in columns 11-20, etc.). A YEAR must be in column 1-4 and not include a decimal point. Data which are percentages, such as the STUDENT GRADUATION PERCENT TABLE or for INFLATE commands, must be punched as fractions. That is 15% is to be punched as .15, etc. (For examples, see Appendix D, Sample Programs.)

B

TAPE CONFIGURATIONS AND RUN INFORMATION

In order to run MSUSIM2 on the MSU 3600 computer system, two tapes are needed. One of these is the data file tape. The other tape contains the MSUSIM2 system. These tapes must be declared with EQUIP cards as shown below.

Four SCOPE control cards are needed to run MSUSIM2. Each of these cards must have a 7 and a 9 punched in column 1. The control card sequence must be as follows:

PNC (Problem number card, issued by the Computer Lab)

$\substack{7\\9}$ JOB, p, id, t, ln, fn

$\substack{7\\9}$ EQUIP, 25 = (DATA TAPE 1, 01, 01, 999), HI, MT (806)

$\substack{7\\9}$ EQUIP, 30 = (MSUSIM 2 ABS), HI, RO, MT (539)

$\substack{7\\9}$ LOADMAIN, 30, t, pr

$$\left\{\begin{matrix}\text{Command}\\\text{Cards}\end{matrix}\right\}$$

The fields on the JOB card are defined as follows;

p: problem number (from PNC card)
id: identification (any user information)
j: job time limit (in minutes)
ln: user's last name
fn: user's first name

The fields on the LOADMAIN card are defined as follows:

t: run time limit (in minutes)
pr: print limit (number of lines)

A time limit of 2 minutes (both JOB and RUN times) and a print limit of 1200 lines are recommended for the first runs. If the user sees that more time and/or print is needed, these limits may be increased.

C

LIST OF COMMANDS

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ONLY COL nn	304
ONLY ROW nn	304
ELEMENT mm nn	304
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COMPUTE ENROLLMENT FROM NEW STUDENTS AID INDEPENDENT	320
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COMPUTE FACULTY	321
DISPLAY FACULTY	323
COMPUTE FACULTY COSTS	321
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D

SAMPLE PROGRAMS

SAMPLE PROGRAM NO. 1

```
COMMENT       THIS PROGRAM ASSUMES THAT A DATA
COMMENT       FILE HAS BEEN PREPARED
COMMENT       WITH TWO FIELDS, 2 LEVELS,
COMMENT       AND 2 RANKS AS SHOWN IN
COMMENT       SAMPLE PROGRAM NO. 3
COMMENT       BRING THE DATA IN TO THE SYSTEM
INITIALIZE FROM DATA FILE
07
COMMENT       SET THE NUMBER OF NEW STUDENTS
HERE IS NUMBER OF NEW STUDENTS AID INDEPENDENT
5000.
COMMENT       PROJECT NEXT YEAR'S ENROLLMENT
COMPUTE ENROLLMENT FROM NEW STUDENTS AID INDEPENDENT
DISPLAY ENROLLMENT
COMMENT       PROJECT AND DISPLAY COSTS
COMPUTE TOTAL COSTS
DISPLAY FACULTY
DISPLAY FACULTY COSTS
DISPLAY TOTAL COSTS
COMMENT       RETURN TO THE PREVIOUS YEAR
BACK YEAR
COMMENT       SEE WHAT WOULD HAPPEN
COMMENT       TO NEXT YEAR'S ENROLLMENT IF TWICE
COMMENT       AS MANY SCHOLARSHIPS ARE OFFERED
INFLATE NUMBER OF SCHOLARSHIPS
ALL
1.0
COMPUTE ENROLLMENT FROM NEW STUDENTS AID INDEPENDENT
DISPLAY ENROLLMENT
COMMENT       RETURN NUMBER OF SCHOLARSHIPS TO
COMMENT       PREVIOUS VALUE
INFLATE NUMBER OF SCHOLARSHIPS
ALL
-.5
COMMENT       RETURN TO PREVIOUS YEAR
BACK YEAR
COMMENT       ASSUME THAT THE MAJOR REQUIREMENTS
COMMENT       FOR FIELD-LEVEL 1 ARE CHANGED SO THAT
COMMENT       MORE FIELD-LEVEL 1 STUDENTS WILL GO INTO
COMMENT       FIELD-LEVEL 4 THAN BEFORE... NOTE THAT
COMMENT       IN THIS EXAMPLE
COMMENT       FIELD-LEVEL 1 CORRESPONDS TO FIELD 1, LEVEL 1,
COMMENT       AND FIELD-LEVEL 4 is FIELD 2, LEVEL 2
```

```
INFLATE STUDENT TRANSITION TABLE
ELEMENT 04 01
.75
COMMENT      PROJECT NEXT YEARS ENROLLMENT AND COSTS
COMPUTE ENROLLMENT FROM NEW STUDENTS AID INDEPENDENT
DISPLAY ENROLLMENT
COMPUTE TOTAL COSTS
DISPLAY FACULTY
DISPLAY FACULTY COSTS
DISPLAY TOTAL COSTS
```

SAMPLE PROGRAM NO. 2

```
COMMENT      THIS PROGRAM ASSUMES THAT A DATA
COMMENT      FILE HAS BEEN PREPARED AS SHOWN IN
COMMENT      SAMPLE PROGRAM 3 BELOW
COMMENT      THIS FILE HAS 2 FIELDS 2 LEVELS AND 2 RANKS
COMMENT      BRING THE DATA IN TO THE SYSTEM
INITIALIZE FROM DATA FILE
07
COMMENT      PROJECT NEXT YEAR'S ENROLLMENT
COMPUTE ENROLLMENT FROM TOTAL NEW STUDENTS
DISPLAY ENROLLMENT
COMMENT      PROJECT COSTS
COMPUTE TOTAL COSTS
DISPLAY FACULTY
DISPLAY FACULTY COSTS
DISPLAY TOTAL COSTS
COMMENT      ASSUME THAT ALL RANK 2 FACULTY
COMMENT      (FIELD-RANKS 2 AND 4) WILL RECEIVE
COMMENT      A 10% RAISE
INFLATE FACULTY SALARY SCALE
ROWS
0.0       0.1       0.0       0.1
COMMENT      PROJECT COSTS AGAIN
COMPUTE TOTAL COSTS
COMMENT      NOTE THAT FACULTY NEED NOT BE
COMMENT      DISPLAYED AGAIN SINCE IT HAS NOT
COMMENT      CHANGED
DISPLAY FACULTY COSTS
DISPLAY TOTAL COSTS
COMMENT      ASSUME THAT NO LABOR COSTS CAN BE
COMMENT      ATTRIBUTED TO THESIS AND
COMMENT      RESEARCH WORK, SO PUT ZERO'S IN
COMMENT      THAT TABLE
INFLATE FRACTION COST OF LABOR FOR THESIS AND RESEARCH
ALL
-1.0
COMMENT      PROJECT COSTS AGAIN
COMPUTE TOTAL COSTS
DISPLAY TOTAL COSTS
```

SAMPLE PROGRAM NO. 3

```
COMMENT      THE PURPOSE OF THIS PROGRAM IS
COMMENT      TO SET UP A DATA FILE ON TAPE
COMMENT      NOTE THAT THE DATA USED IS
COMMENT      DUMMY
COMMENT      SET THE SYSTEM FOR 2 FIELDS
COMMENT      2 LEVELS AND 2 RANKS
ESTABLISH BACKGROUND
020202
COMMENT      CALL THIS YEAR 1963
HERE IS YEAR
1963
COMMENT      SET UP DESCRIPTIONS OF FIELDS
COMMENT      LEVELS AND RANKS
DESCRIPTION OF FIELDS
ENGINEERNON-ENGR
DESCRIPTION OF LEVELS
UNDERGRADGRADUATE
DESCRIPTION OF RANKS
LOWRANK HIGHRANK
COMMENT      INPUT DATA FOR THE STUDENT SECTOR
HERE IS STUDENT GRADUATION PERCENT TABLE
.16     .40     .16     .40
HERE IS STUDENT ASSISTANTSHIP ATTRACTION TABLE
1.0     1.0     1.0     1.0
HERE IS STUDENT SCHOLARSHIP ATTRACTION TABLE
1.0     1.0     1.0     1.0
HERE IS STUDENT ASSISTANTSHIP RETENTION TABLE
.30     .25     .04     .03     .20     .30     .03     .04
.02     .01     .15     .10     .01     .02     .20     .15
HERE IS STUDENT SCHOLARSHIP RETENTION TABLE
.30     .15     .02     .01     .30     .20     .01     .01
.01     .02     .20     .30     .01     .03     .30     .20
HERE IS RESEARCH GRANTS
800.0     4500.0
HERE IS ENROLLMENT
2500.     500.     21000.     7000.
HERE IS STUDENT TRANSITION TABLE
.60     .0     .005     .0     .02     .20     .001     .0
.001    .0     .50      .0     .001    .0      .03     .30
HERE IS DEMAND FOR TEACHING ASSISTANTSHIPS
.0     .0     .0     .0     .001     .0     .0     .0
.0     .0     .0     .0     .001     .0     .001   .0
HERE IS DEMAND FOR RESEARCH ASSISTANTSHIPS
.0     .0     .04    .0     .0     .0     .0     .04
HERE IS PERCENT BREAKDOWN OF NEW STUDENTS AID INDEPENDENT
.1     .02     .66     .22
HERE IS NUMBER OF SCHOLARSHIPS
150.     75.     1500.     850.
```

```
HERE IS NUMBER OF NEW STUDENTS AID INDEPENDENT
10000
HERE IS DEMAND FOR CREDIT HOURS
20.      5.      0.      0.      1.      25.      0.      0.
20.      1.      38.     5.      0.      1.       2.      35.
HERE IS NUMBER OF TOTAL NEW STUDENTS
13000
HERE IS PERCENT BREAKDOWN OF TOTAL NEW STUDENTS
.10     .02     .66     .22
COMMENT       INPUT DATA FOR THE FACULTY SECTOR
HERE IS EFFORT FOR UNDERGRADUATE INSTRUCTION
.0009     .0     .0     .0     .0     .001     .0     .0
.0        .0     .001   .0     .0     .0       .0006  .0
HERE IS EFFORT FOR GRADUATE INSTRUCTION
.0     .0011     .0     .0     .0     .0012     .0     .0
.0     .0        .0     .0011  .0     .0        .0     .0008
HERE IS EFFORT FOR UNDERGRADUATE ADVISING
.0002     .0     .0     .0     .0001     .0     .0     .0
.0        .0     .0001  .0     .0        .0     .0005  .0
HERE IS EFFORT FOR GRADUATE ADVISING
.0     .0007     .0     .0     .0     .0006     .0     .0
.0     .0        .0     .0007  .0     .0        .0     .0006
HERE IS EFFORT FOR THESIS AND SUPERVISION
.0     .005     .0     .0     .0     .007     .0     .0
.0     .0       .0     .0007  .0     .0       .0     .0005
HERE IS EFFORT FOR RESEARCH
.02     .0     .03     .0     .0     .04     .0     .05
HERE IS EFFORT FOR UNDERGRADUATE COURSE DEVELOPMENT
.04     .05     .02     .04
HERE IS EFFORT FOR GRADUATE COURSE DEVELOPMENT
.03     .02     .03     .03
HERE IS EFFORT FOR PUBLIC SERVICE
.01     .01     .01     .01
HERE IS EFFORT FOR SEMINARS AND MEETINGS
.03     .04     .04     .04
HERE IS EFFORT FOR ADMINISTRATION
.03     .04     .04     .04
HERE IS EFFORT DISTRIBUTION TABLE
.86     .84     .86     .84
HERE IS FRACTION COST OF SUPPLIES AND SERVICES FOR UNDERGRADS
.50     .50
HERE IS FRACTION COST OF SUPPLIES AND SERVICES FOR GRADS
.20     .20
HERE IS FRACTION COST OF SUPPLIES AND SERVICES FOR THESIS AND RESEARCH
.30     .30
HERE IS FRACTION COST OF LABOR FOR UNDERGRADS
.30     .30
HERE IS FRACTION COST OF LABOR FOR GRADS
.20     .20
HERE IS FRACTION COST OF LABOR FOR THESIS AND RESEARCH
.5      .5
```

```
HERE IS FRACTION COST OF SECRETARIES FOR UNDERGRADS
.4        .4
HERE IS FRACTION COST OF SECRETARIES FOR GRADS
.2        .2
HERE IS FRACTION COST OF SECRETARIES FOR THESIS AND RESEARCH
.4        .4
HERE IS FRACTION COST OF EQUIPMENT FOR UNDERGRADS
.5        .5
HERE IS FRACTION COST OF EQUIPMENT FOR GRADS
.3        .3
HERE IS FRACTION COST OF EQUIPMENT FOR THESIS AND RESEARCH
.2        .2
HERE IS COST OF SECRETARIES
100000.0            900000.0
HERE IS COST OF LABOR
70000.0   400000.0
HERE IS COST OF SUPPLIES AND SERVICES
12000.0   150000.0
HERE IS COST OF EQUIPMENT
20000.0   150000.0
HERE IS FACULTY SALARY SCALE
12000.0   14000.0   10000.0   12000.0
HERE IS ASSISTANTSHIP SALARY SCALE
2800.0    2800.0
COMMENT        WRITE THE PARAMETERS ONTO THE
COMMENT        TAPE AS FILE 7
AUGMENT DATA FILE
07
THIS FILE CONTAINS DUMMY DATA
```

4
Blank
Cards

4:5.3.2 Technical Description of MSUSIM2

This section contains the equations taken from the theoretical model, definitions of the notation used in the program, a description of each subroutine (page 348), and a description of the data tape manipulation (page 369).

MSUSIM2 is the name used to denote program MASTER and its associated subroutines. MSUSIM2 is written in the CDC 3600 FORTRAN language. Because a large amount of matrix manipulation is involved in the calculations to be performed, a package of subroutines for matrix manipulation is utilized. This package is called BUMP (Basic Utility Matrix Package) and was written in 3600 COMPASS and FORTRAN at the University of Wisconsin. This package allows matrices to be stored as type general (entire matrix is stored), type symmetric (not used by MSUSIM2), or type diagonal (diagonal entries stored as a vector). It should be noted that some parameters described in the User's Manual as column vectors are sometimes actually used as row vectors or as diagonal matrices, in order to allow the computation to be most easily expressed. BUMP allows MSUSIM2 the freedom to supply reduced matrix dimensions as part of a call, even when the matrix is declared full-size in the calling program.

Certain incompatibilities exist between 3600 FORTRAN and ASA FORTRAN. In addition to the modifications which BUMP would require to run on a different type computer, other parts of MSUSIM2 would require limited modification (for example, 8 character A fields are used); however, the changes which would be required are straightforward with the possible exception of the tape handling calls which are used in subroutine INITIL.

MASTER is the main program in the MSUSIM2 system. Its function is the reading and decoding of commands and the calling of subroutines to perform the operations indicated. MASTER operates in two distinct modes--normal and DEBUG. In DEBUG mode, certain commands are not executed but only checked for legality and passed over. The purpose of this mode is to allow the user to find all his errors in as few passes as possible. This feature is implemented through the use of a flag, IDEBUG, which, when set, prevents the setting of the error flag IERROR in subroutine RECOVER.

Each time a new command is to be read in, MASTER reads a card into array KEY according to the format (A8,A5,A1,8A8,A2). The first word of KEY (i.e., the first 8 characters on the card) serves as the principal or top-level command. Decoding includes first a check to determine whether the program has processed an error from which it has not yet recovered. If so, only the RECOVER card is processed--any other command is totally ignored. If not, the decoding proceeds with the printing of the command if the program is in list mode (ILIST = 1). The first word is now compared with each possible legal first word--if a match is found, control is transferred to a statement to further decode or execute the command; if not, the command is erroneous, so RECOVER is called, and an error message is printed. Then the program continues by reading the next command.

The remaining sections of MASTER perform the operations dictated by the command which causes control to be given to them. They will be described in the order they appear in MASTER. Each section ends in a return of control to the command-reading section.

RECOVER section -- resets error flag IERROR to 0.

INITIALIZE FROM DATA FILE and ESTABLISH BACKGROUND section -- reads NF, NL, NR. If NL = 0, command was INITIALIZE FROM DATA FILE, so it sets NFIL = NF, blocks execution of BACK YEAR and calls INITIL. If NL = 0, command was ESTABLISH BACKGROUND, so it zeroes parameters, prepares field, level, and rank labels, and calculates NFL and NFR.

BACK YEAR section checks for possibility of back-up, prints message if impossible. If possible, it sets enrollment to last year's enrollment.

INFLATE section -- reads secondary command, lists if in list mode, decodes secondary command,sets IOKEY, then jumps to common parameter decoding section for INFLATE, READ IN, SHOW ME, and HERE IS for the decoding to call proper I/O routine.

SHOW ME section -- sets IOKEY, jumps to common parameter decoding section.

HERE IS section -- sets IOKEY, jumps to common parameter decoding section.

READ IN section -- sets IOKEY, begins common parameter decoding section.

COMPUTE section -- decodes remainder of command and calls proper routine or calls RECOVER if not decodable. Does nothing if debugging.

DISPLAY section -- decodes remainder of command and calls proper routine or calls RECOVER if not decodable. Does nothing if debugging.

LIST COMMANDS sections -- sets list flag, lists itself.

NO LIST section -- resets list flag.

DESCRIPTION section -- decodes further, reads in descriptions.

AUGMENT section -- reads file number to be added, lists if necessary, calls AUGMNT. If debugging, AUGMNT reads the label cards but does not augment the data tape.

DELETE section -- reads file number to be deleted, lists if necessary, calls DELETE if not debugging.

UPDATE DATA FILE section -- reads file number, lists if necessary, calls UPDATE if not debugging.

Q25QINIT section -- calls NEWMT unless debugging.

Q25QCOPY section -- calls COPY unless debugging.

LIST DATA FILE section -- calls LIST unless debugging.

HEADING section -- does nothing if in list mode. Otherwise, blanks first word of command (HEADING) and lists command.

DEBUG section -- sets IDEBUG flag = 1.

COMPENRL is the computation subroutine for the student sector. It computes the enrollment for year t from data for year t-1 in one of two ways depending on which entry point of COMPENRL is called by MASTER. A COMPUTE ENROLLMENT FROM NEW STUDENTS AID INDEPENDENT command will cause MASTER to call entry point COMPENRL and a COMPUTE ENROLLMENT FROM TOTAL NEW STUDENTS will cause MASTER to call entry point COMPEN 2. A call to entry point COMPENRL will cause the projected enrollment, STPL1 to be calculated with the following equation:

STPL1 = (I+K1* G1* C) (P * ST + AT * NT + K1 * G3 * OT + K2 * HT)

In the notation of the system model, this equation is written

$$s(t) = (I+K_1G_1C) \ (Ps(t-1)) + a(t)n(t) + K_1G_3o(t) + K_2h(t).$$

The multiplication K2 + HT determines the number of students attracted to each field and level by scholarships. K1 * G3 * OT determines the number of research assistants attracted to each field and level. OT is in thousands of dollars of research. G3 is in units of assistantships per 1000 dollars of research and K1 is in units of students per assistantship. AT * NT breaks the new students independent of financial aid into fields and levels. P * ST determines the field and level of the students for year t who were in the university at year t-1. Then these terms are summed to give an intermediate enrollment for year t. The number of teaching graduate assistants necessary to form a complement to the faculty is a function of this intermediate enrollment. The intermediate enrollment is multiplied by the C matrix to determine how many credits will be demanded in each field and level by the intermediate enrollment. Then the product is multiplied by G1 which determines the number of graduate teaching assistants necessary for that number of credits. Then this product is multiplied by K1 to determine the number of students that are attracted by teaching assistantships. This is added to the intermediate enrollment to give the complete enrollment for year t.

It could be assumed that these teaching graduate assistants require further graduate assistants because of the credits they will demand, but a loop is developed by this assumption. Furthermore, the added graduate credits will produce only a very minor demand for graduate assistants. Therefore, for the purposes of avoiding the loop and because the added demand is so small, it is assumed in this model that the attracted graduate assistants will demand no other graduate assistants.

The third step at entry point COMPENRL is to compute the number of students who left the university before year t for any reason. This is done by the equation

$$DT = D*ST - [H1 * G1 * C * STPL1 + H1 * G3 * OT + H2*HT]$$

or in the notation of the systems model

$$d(t) = Ds(t-1) - [H_1G_1Cs(t) + H_1G_3o(t) + H_2h(t)].$$

The diagonal D matrix is formed by summing the columns of the P matrix and subtracting that sum from one, i. e.

$$Dii = 1 - \sum_j P_{ij}.$$

This gives the proportion of students in each field and level who would leave the university if it were not for financial aid. The product D * ST gives the actual number of students in each field and level who would depart. Subtracted from this is the number of students in each field and level who are induced to stay because of financial aid. The number induced to stay is the sum of H2 * HT, the number induced to stay by scholarships; H1 * G3 * OT, the number induced to stay by research assistantships; and H1 * G1 * C * STPL1, the number induced to stay by teaching assistantships. This subtraction gives the number of students who will depart before year t.

The second step at entry point COMPENRL is to compute the students carrying over from year t-1 to year t by the equation

CO = P * ST + L1 * G1* C* STPL1 + L1 * G3 * OT + L2 * HT

or in the notation of the systems model

$$S_{co}(t) = Ps(t-1) + L_1G_1Cs(t) + L_1G_3o(t) + L_2h(t).$$

The number of "carry overs" in a given field and level is the number of students in that field and level at year t who were in the university at year t-1 in any field and level. L1 and L2 are the diagonal matrices formed by the column sums of H1 and H2 respectively, i. e., $L1_{ii} = \sum_{j} H1_{ij}$. They are the proportion of students who go to each field and level in year t who would not go to that field and level if it were not for financial aid.

The product L2 * HT gives the number of students in each field and level who go to that field and level because of scholarships. L1 * G3 * OT are the students who go to each field because of research assistantships and L1 * G1 * C * STPL1 are the students who go to each field and level because of teaching assistantships. These terms are summed and added to P * ST to give the carry-overs.

The next step at COMPENRL is to compute the number of new students in each field and level with the equation

ATP * NTP = STPL1 - CO.

This includes new students independent of aid and new students because of aid. This is described as a product because it can be considered as a scalar number of new students broken down into fields and levels by multiplying it by a distribution vector. This concept is the same as the multiplication of NT, the number of new students independent of aid, by the distribution vector AT as was described previously. ATP * NTP is calculated by subtracting the number of students who carry over to each field and level in year t from the number of students in each field and level, and this gives the number of students new to the university in each field and level.

Then the number of new students due to aid in each field and level is calculated by the equation

$$NSWA = ATP * NTP - AT * NT.$$

AT * NT is the number of new students in each field and level independent of aid. ATP * NTP is the total number of new students in each field and level,and the subtraction gives the number of new students attracted to each field and level by aid.

The next step at COMPENRL is to compute the number of students in each field and level who graduated in year t-1 by the equation

$$GT = GR * ST.$$

GR is a diagonal matrix with the elements on the diagonal being the proportion of students who graduate from each field and level within a given year. The students who graduate and leave the university are included in the number of students who depart, which was described previously. But not all students who graduate depart from the university. Additional information is also obtained from previous calculations. C*STPL1 gives the projected demand for credits. This multiplication is done in determining the number of students who depart. Also AT*NT provides the number of new students in each field and level independent of aid. Both of these products are saved and are available for output with the final products from the subroutine.

The call to entry point COMPENRL computed the enrollment projection with the number of new students aid independent, NT, by computing the number of new students because of aid and adding the two to get the number of total new students. An alternate method is to compute the enrollment projection from the number of total new students breaking this into aid-independent and because-of-aid categories.

It is this latter procedure that is executed at entry point COMPEN2. This procedure is implemented by computing AT*NT from ATP*NTP and then following the procedure of entry point COMPENRL as much as is possible or necessary. The equation for

AT*NT = NSWO

is

NSWO = ATP*NTP - [K1 - L1] [G3*OT + G1*C[P*ST + ATP*NTP + L1*G3* OT + L2*HT]] - [K2-L2]*HT.

In the notation of the systems model

$$a(t)\,n(t) = a'(t)n'(t) - [K_1 - L_1]\ [G_3 o(t) + G_1 C]\ Ps(t) + a'(t)n'(t) + L_1 G_3\ o(t) + L_2 h(t)\ ]\ ] - [K_2 - L_2]\,h(t).$$

This equation computes the number of new students attracted by aid in each field and level and subtracts this from ATP*NTP to give the new students independent of aid in each field and level. K1 and K2 are the assistantship and scholarship attraction tables. They apply to both the new students and students presently in the university. L1 and L2 apply only to students presently in the university, so the subtraction K2 - L2 will give the new student scholarship attraction table and [K2 - L2]*HT will be the number of new students in each field and level attracted by scholarships.

The product L2*HT will give the number of students who were in the university at year t-1, who are attracted to each field and level by scholarships offered for year t. L1*G3*OT is the number of students attracted to each field and level in year t by research grants offered for year t who were in the university at year t-1. ATP + NTP is the number of total new students in each field and level; P*ST is the transition of students in the university from year t-1 to the year t without the effects of financial aid. Then the terms P*ST, ATP*NTP, L1*G3*OT, and L2*HT are summed to give an intermediate enrollment much in the same way as in computing STPL1 in COMPENRL. This is then multiplied by C to give the demand for credits by the intermediate enrollment, and this product is multiplied by G1 to give the number of teaching assistantships that will be offered because of the intermediate enrollment. To this is added the number of research assistantships to be offered, G3*OT. This is then multiplied by (K1-L1) to give the number of new students in each field and level attracted by assistantships. Then [K2-L2]*NT which was computed earlier is added to the number of new-because-of-assistantships to give the total number of new students attracted by financial aid in each field and level. This is subtracted from the total number of new students to give the new-students-aid-independent.

The computation then proceeds exactly as at entry point COMPENRL with the exceptions of computing carry-overs and numbers of total new students.

The carry-overs are computed by the equation

$$CO = STPL1 - ATP*NTP,$$

which is the enrollment at year t minus the new students in year t.

The total number of new students in each field and level is obtained directly from the given variables at entry COMPEN2 and need not be computed separately as at COMPENRL.

FTE is the computational subroutine that is indirectly called by a COMPUTE FACULTY command. It computes the number of faculty, in full-time equivalents, or FTEs, required for the demands upon the faculty of the university at the time FTE is called. It also computes the number of teaching and research assistants required. The faculty is computed by computing the FTEs necessary for various activities and summing these to give the complete faculty in FTEs.

The number of FTEs needed for undergraduate and graduate instruction depends on the demand for credit hours made by the enrollment. This demand is computed by

$$CT = C*ST.$$

This yields a vector, CT, containing the number of student credit hours demanded in each field and level. Then the FTEs for undergraduate instruction are computed by

$$FTEUGI = FUGI*CT.$$

FUGI contains the proportions of effort that an average faculty member in each field and rank spends on undergraduate instruction in each field. This multiplication will give the number of FTEs for undergraduate instruction in each rank and field.

The number of FTEs for graduate instruction is computed in the same way by the equation

$$\mathrm{FTEGI} = \mathrm{FGI}*\mathrm{CT}.$$

The number of FTEs necessary for undergraduate and graduate advising and for thesis supervision depends on the enrollment. The FTEs for undergraduate advising are computed by the equation

$$\mathrm{FTEUGAD} = \mathrm{FUGAD}*\mathrm{ST}.$$

FUGAD contains the effort spent (by the average faculty member in each field and rank) on undergraduate advising per student in each field and level. Therefore, the multiplication gives the FTEs for undergraduate advising. The equation

$$\mathrm{FTEGAD} = \mathrm{FGAD}*\mathrm{ST}$$

computes the FTEs for graduate advising and

$$\mathrm{FTETHS} = \mathrm{FTHS}*\mathrm{ST}$$

yields the FTEs for thesis supervision.

The FTEs for research depend on the amount of contracted research in thousands of dollars. These are computed by the equation

$$\mathrm{FTERES} = \mathrm{FRES}*\mathrm{OT}.$$

These computed FTEs are then summed into the array FTP. But FTP is only a part of the total FTEs spent in each field and rank. Next the total FTEs in each field and level, given the above subtotal, are computed. FCW is the average percent of FTP spent on committee work by the faculty in each field and rank. Multiplying FCW by FTP, yields the total FTEs spent on committee work by faculty of each field and rank. A further breakdown of the total FTEs is obtained in the same way by the following equations: FTEs for undergraduate course development:

$$\mathrm{FTEUGCD} = \mathrm{FUGCD}*\mathrm{FTP}$$

FTEs for graduate course development:

$$FTEGCD = FGCD*FTP$$

FTEs for public service:

$$FTEPS = FPS*FTP$$

FTEs for administration:

$$FTEADM = FADM*FTP$$

FTEs for seminars and meetings:

$$FTESM = FSM*FTP.$$

These FTEs are added to the FTEs accounted for by response to the demands above to obtain the total FTEs required, using the equation $FT = FTP + FTECW + FTEUGCD + FTEGCD + FTEPS + FTESM + FTEADM$.

Also computed are the number of teaching and research assistants required to complement the faculty by the equations

$$Y = G1*C*ST \text{ and } Z = G3*OT.$$

These equations are described in the section on subroutine COMPENRL. Y and Z contain the number of assistantships to be offered in each field and level. These are then condensed into the number of assistantships offered in each field. Y is condensed into TGAT and Z is condensed into RGAT.

FACT is the subroutine that computes the costs which result directly from faculty salaries. The direct undergraduate costs due to faculty salaries are computed with the equation

$$DUGC = (FTEUGI + FTEUGAD + FTEUGCD)*FH.$$

FH is the vector containing the average faculty salaries for each field and rank, and the variables summed give the total FTEs directly related to undergraduate demands. The multiplication thus gives the undergraduate costs due to faculty salaries for each field and rank.

The direct graduate costs and direct thesis and research costs are computed in the same way as above with the equations

$$DGC = (FTEGI + FTEGAD + FTEGCD)*FH$$

and

$$THRES = (FTETHS + FTERES)*FH.$$

The remaining FTEs cannot be related directly to undergraduate, graduate or thesis and research demands. They are grouped to give direct cost of other activities due to faculty salaries by the equation

$$OPOH = (FTECW + FTEPS + FTESM + FTEADM)*FH.$$

Then to obtain total costs due to faculty salaries, the faculty salary scale vector is multiplied by the total FTEs of each field and rank

$$TFS = FT*FH.$$

This yields the total faculty salaries.

DPTC is the routine that computes the total costs for each field. It is called by MASTER in the event of a COMPUTE TOTAL COSTS command. Because the information from subroutines FTE and FACT is necessary to DPTC, a call to FTE, then to FACT is made by MASTER before DPTC is called.

The first items computed in DPTC are the graduate teaching and graduate research assistant costs. This is done by the equation

$$GTC = GH*TGAT$$

and

$$GRC = GH*RGAT.$$

GH is the assistantship salaries for each field, and TGAT and RGAT are the number of teaching and research assistants in each field. Thus the multiplications give the costs of research and teaching assistantships in each field. The undergraduate overhead is then computed by the equation

$$\mathrm{UGOH} = \mathrm{SEC} * \mathrm{SECUG} + \mathrm{RLAC} * \mathrm{RLACUG} + \mathrm{EQC} * \mathrm{EQCUG} + \mathrm{SSC} * \mathrm{SSCUG}.$$

SEC is the cost of secretaries for each field, and SECUG is the proportion of the cost of secretaries in each field which resulted from work related to undergraduate studies. The multiplication SEC*SECUG yields the cost of secretaries in each field resulting from undergraduate work. The other terms are of the same type as the secretaries' costs. RLAC is the cost of labor for each field, and RLACUG is the proportion of those costs devoted to undergraduate work. EQC is the costs of equipment; SSC is the costs of supplies and services. Thus when these are multiplied by their proportion costs and summed, they give the undergraduate overhead. The graduate overhead and thesis and research overhead are computed in exactly the same way with the equations

$$\mathrm{GOH} = \mathrm{SEC} * \mathrm{SECG} + \mathrm{RLAC} * \mathrm{RLACG} + \mathrm{EQC} * \mathrm{EQCG} + \mathrm{SSC} * \mathrm{SSCG}$$

and

$$\mathrm{TROH} = \mathrm{SEC} * \mathrm{SECTR} + \mathrm{RLAC} * \mathrm{RLACTR} + \mathrm{EQC} * \mathrm{EQCTR} + \mathrm{SSC} * \mathrm{SSCTR}.$$

These overheads may be incomplete. For example, a proportion of the secretarial costs may not come directly from undergraduate work, graduate work, or thesis and research work. To determine this proportion, the three fractional costs of secretaries for each field are summed and each of these sums is subtracted from one (1). Then this vector is multiplied by SEC to determine the cost of secretaries for other activities for each field.

In the same way the three fractional costs for the labor, equipment, and supplies and services are summed and then subtracted from one.

Then each of these derived quantities is multiplied by the proper cost vector to obtain the cost of labor, equipment, and supplies and services for other activities. The equations for the above operations are:

cost of secretaries for other activities = SEC*(1 - (SECUG + SECG + SECTR))
cost of labor for other activities = RLAC*(1-RLACUG + RLACG + RLACTR)
cost of equipment for other activities = EQC*(1-(EQCUG + EQCG+ EQCTR))
cost of supplies and services for other activities = SSC*(1-(SSCUG + SSCG + SSCTR)).

These are summed to obtain OHM, the overhead costs of other activities.

The costs have been broken down into three major categories: undergraduate, graduate, and thesis and research; and several cost breakdowns have been made in each of these categories. To determine the total undergraduate cost, all costs related to undergraduate work, including cost of faculty, are summed by the equation

$$TUG= UGOH + RNUGC + GTC.$$

The graduate teaching assistant costs, GTC, are included in this equation because it is assumed that the assistants teach only undergraduate courses. The total costs of other activities is computed by

$$TM = RNOPOH + OHM.$$

These costs are then summed to give the grand total costs for each field. The equation is

$$TOTCST = TUG + TG + TTR + TM.$$

Subroutine RECOVER is used when an error is detected. It prints

```
***** USER ERROR ***** ***** THERE IS AN ERROR IN OR PRECEDING
THE COMMAND SHOWN BELOW *****
```

Array KEY (the command) is printed next.

If IDEBUG is 1 (the DEBUG option) the routine ends. Otherwise IERROR is set to 1 and the routine ends.

Subroutine NREAD handles READ IN, HERE IS, SHOW ME, and INFLATE when KEY (3) (column 14) contains an N. If KEY (6) (columns 31-38) contains "ATTRACTI", "TRACTIØN", RETENTIØ", TENTIØN", "LE∧∧∧ ∧∧", "EW∧ STUDE", "ØTAL∧NEW", or "CENT∧TAB": then NREAD sets IGO to 1, 2, 3, 4, 5, 6, 7, or 8 respectively.

Then IOKEY, furnished by MASTER, is checked. If IOKEY is -1 (READ IN) or 0 (HERE IS), reading is done. If IOKEY is 1 (SHOW ME) or greater (INFLATE), the reading section is skipped.

In the reading section, IGO specifies which of the 8 calls to MXREAD will be used. The calls use as first parameter the array name K1, K2, H1, H2, P, AT, ATP, or GR. (These names correspond to student assistantship attraction table, student scholarship attraction table, student assistantship retention table, student scholarship retention table, student transition table, student graduation percent table, percent breakdown of new students aid-independent, and percent breakdown of total new students, respectively.)

Now, if IOKEY is -1 the routine ends. Othersie, if IOKEY is greater than 1 (INFLATE), the printing section is skipped and the inflate section is used.

The printing section is the same as the reading section except MXPRINT is used where MXREAD was before. One dimensional arrays will be printed in rows instead of columns to conserve space. When printing is finished, the inflate section is bypassed and the routine ends.

The inflate section checks IGO to determine which call to SMULT will be used. The 8 calls use K1, K2, H1, H2, P, AT, ATP, or GR as the first parameter to correspond to IGO equaling 1, 2, 3, 4, 5, 6, 7, or 8. The routine then ends.

Subroutine R READ handles READ IN, HERE IS, SHOW ME, and INFLATE when KEY (3) (column 14) contains R, L or blank. If Key (14) (columns 15-22) contains "CH∧GRANT", "MENT∧∧∧∧", "∧OF∧SCHO", "∧OF∧NEW∧", or "∧OF∧TOTA" then IGO is set to 1, 2, 3, 4, or 5 respectively. If KEY (2) (columns 9-13) contains "YEAR∧", IGO is set to 6. If none of the six conditions is met, RECOVER is called and nothing else is done.

Then I0KEY, furnished by MASTER, is checked. If IOKEY is -1 (READ IN) or 0 (HERE IS) reading is done. If IOKEY is 1 (SHOW ME) or greater (INFLATE), the reading section is skipped.

On the reading section IGO specifies which of the six input statements will be used. The first three call MXREAD, specifying vector name OT (research grants array), ST (enrollment array), or HT (number of scholarships array). The other three input statements read the value for NT (new students aid independent), NTP (total new students), or IYEAR (year).

Now, if IOKEY is -1 the routine ends. Otherwise, if IOKEY is greater than 1 (INFLATE), the printing section is skipped and the inflate section is used.

The printing section is the same as the reading section except MXPRINT is used where MXREAD was before. Vectors will be printed in rows instead of by columns to conserve space. When printing is finished the inflate section is bypassed and the routine ends.

The inflate section checks IGO to determine which call to SMULT will be used. The five calls use OT, ST, HT, NT, or NTP as the first parameter to correspond to IGO equaling 1 to 5. If IGO is 6 (IYEAR), SMULT is not called. The routine then ends.

Subroutine DREAD, used when KEY (3) (column 14) contains D, is the same as NREAD except IGO varies from 1-3 if KEY (5) (columns 23-30) is "CHING AS", "EARCH AS", or "DIT HOUR", and G1, G3, and C are the array names (corresponding to demand for teaching assistants, demand for research assistants, and demand for credit hours).

SUBROUTINE FINP, used when KEY (3) (column 14) contains T, is the same as NREAD except IGO varies from 1-5 if KEY (6) (columns 31-38) is "TE∧INSTR", "STRUCTIO", "TE∧ADVIS", "VISING∧∧", or "RVISION∧"; IGO is 6 if KEY (5) (columns 23-30) is "EARCH∧∧∧"; IGO varies from 7-13 if KEY (6) is "ORK∧∧∧∧∧", "TE∧COURS", "URSE∧DEV", "ICE∧∧∧∧∧", "D∧MEETIN", "ION∧∧∧∧∧", or "BLE∧∧∧∧∧"; IGO is 14 if KEY (5) is "∧SCALE∧∧", and IGO is 15 if KEY (6) is "CALE∧∧∧∧".

FUGI, FGI, FUGAD, FGAD, FTHS, FRES, FCW, FUGCD, GFCD, FPS, FSM, FADM, K, FH, and GH are the array names corresponding to effort for undergraduate instruction, effort for graduate instruction, effort for undergraduate advising, effort for graduate advising, effort for thesis supervision, effort for research, effort for committee work, effort for undergraduate course development, effort for graduate course development, effort for public service, effort for seminars and meetings, effort for administration, effort distribution table, faculty salary scale, and assistantship salary scale.

Subroutine KRV, used when KEY (3) (column 14) contains I or

0, is the same as NREAD except I GO varies from 1-3 if KEY (8) (columns 47-54) is "∧FOR∧UND", "∧FOR∧GRA", or "∧FOR∧THE"; I GO varies from 4-12 if KEY (7) (columns 39-46) is "OR∧UNDER", "OR∧GRADS", "OR∧THESI", "ERGRADS∧", "DS∧∧∧∧∧∧", "SIS∧AND∧", "∧UNDERGR", "∧GRADS∧∧", or "∧THESIS∧"; and IGO varies from 13-16 if KEY (4) (column 15-22) is "F∧SECRET", "F∧LABOR∧", "F∧SUPPLI", or "F∧EQUIPM".

SSCUG, SSCG, SSCTR, SECUG, SECG, SECTR, RLACUG, RLACG, RLACTR, EQCUG, EQCG, EQCTR, SEC, RLAC, SSC and EQC are the array names corresponding to fractional cost of supplies and services for undergrads, - for grads, - for thesis and research; fractional cost of secretaries for undergrads, - for grads, - for thesis and research; fractional cost of labor for undergrads, - for grads, - for thesis and research; fractional cost of equipment for undergrads, - for grads, - for thesis and research; cost of secretaries; cost of labor, cost of supplies and services; and cost of equipment.

STOUTPUT is the output subroutine for the student sector. It is called by MASTER in the event of DISPLAY ENROLLMENT command. It prints the following variables and results:

ST, the enrollment projection for year t;

SO, the enrollment for year t-1;

CO, the students who carry over to year t;

OT, the students who depart;

OT, research grants in thousands of dollars by field;

GT, the students who graduate in each field and level;

CT, the projected demand for credit hours;

HT, the number of scholarships offered for year t;

NSWA, the number of new students aid independent;

NSWO, the number of new students by aid;
IYEAR, year t; and
IYRM1, year t-1.

Each of these results is summed over field and level and these totals are also printed. The display is in table form with labels for the results along the top and field-level labels along the side. Since the array OT is an NFx1 and all the other printed arrays are NFLx1, the element of OT corresponding to field i is printed in the line corresponding to field i level 1. The display always starts at the top of a page and six lines are skipped after the display.

PFTE is a subroutine called from program MASTER to print the output created by the DISPLAY FACULTY command. The total display is divided into two parts: the first part to display the total number of faculty (in FTEs) in each field and rank and the second part to display the number of Research and Teaching assistantships for each field. First, a two-line heading for the first part of the display (including the current year, IYEAR) is printed. Then, the names of the fields, IFLAB, are printed out as headings for the individual columns. Next the WRITE statement is executed once for each rank of faculty, and (1) the heading for the rank of faculty (IRLAB) and (2) the total number of faculty (in FTEs) for the specified field and rank is printed.

Another heading, for the second part of the display (again including the current year) (IYEAR), is then printed out, followed by the printing of the names of the fields (IFLAB) as headings for the individual columns of figures. The next WRITE statement causes the printing of (1) the heading, RESEARCH, and (2) the total number of research assistantships (RGAT) for each field. The next WRITE statement prints (1) the heading, TEACHING, and (2) the total number of teaching assistantships (TGAT) for each field. The subroutine then skips 7 lines before branching control back to the main program.

PFAC is a subroutine called from program MASTER to print the output created by the DISPLAY FACULTY COSTS command. First, a 2-line heading for the entire display is printed after skipping down to the nearest of lines 4, 23 or 42. Then two line headings for the individual columns of the figures are printed. Next a series of 2 DO-loops is set up to print out the actual display. The outer loop is passed through once for each field, and the inner loop once for each rank of faculty. Therefore, the total number of lines printed is the number of fields times the number of ranks. The WRITE statement prints (1) the heading for the field (IFLAB), (2) the heading for the faculty rank (IRLAB), (3) the calculated value of the direct undergraduate costs for the specified field and rank of faculty (DUGC), (4) the calculated value of the direct graduate costs for the specified field and rank of faculty (DGC), (5) the calculated value of the costs for thesis and research for the specified field and rank of faculty (THRES), (6) the calculated total for other activities for the specified field and rank of faculty (OPOH), and (7) the calculated value of total faculty salaries for the specified field and rank of faculty (TFS). The subroutine then skips 7 lines before branching control back to the main program.

PDPT is a subroutine called from program MASTER to print the output created by the DISPLAY TOTAL COSTS command. First, a heading (including the current year, IYEAR) for the entire display is centered and printed after skipping to the nearest of lines 4, 23 or 42. Then, the names of the fields (IFLAB) are printed out as headings for the individual columns of figures. The next 11 WRITE statements print the following information (by lines): (1) the heading UNDERGRADUATE OVERHEAD followed by the calculated overhead for undergraduates (UGOH) in each of the specified fields; (2) the heading GRADUATE OVERHEAD followed by the calculated overhead for graduate students (GOH) in each of the specified fields; (3) the heading THESIS + RESEARCH OVERHEAD followed by the calculated overhead for thesis and research (TROH) for each of the specified fields; (4) the heading OVERHEAD FOR OTHER ACTIVITIES followed by the calculated overhead for other activities (OHM) for each of the specified fields; (5) the heading TEACHING ASSISTANT COSTS followed by the calculated costs for teaching assistantships (GTC) for each of the specified fields; (6) the heading RESEARCH ASSISTANT COSTS followed by the calculated costs for research assistantships (GRC) for each of the specified fields; (7) the heading TOTAL UNDERGRADUATE COSTS followed by the calculated values of total undergraduate costs (TUG) for each of the specified fields; (8) the heading TOTAL GRADUATE COSTS followed by the calculated values of total graduate student costs (TG) for each of the specified fields; (9) the heading TOTAL THESIS and RESEARCH COSTS followed by the calculated values of total thesis and research costs (TTR) for each of the specified fields; (10) the heading TOTAL COSTS, OTHER ACTIVITIES followed by the calculated values for total costs for other activities (TM) for each of the specified fields, and (11) the heading TOTAL COSTS followed by the calculated values for total costs (TOTCST) for each of the specified fields. The zero appearing at the beginning of the output formats printing TTR, TG, TUG, etc., is the carriage control indicating standard one line spacing.

The subroutine then skips 7 lines before branching control back to the main program.

SMULT is the subroutine that modifies the parameters of the system. It is called from one of the I/O routines which is called from MASTER in the event of an INFLATE command. It takes as parameters from the I/O routine A the array to be modified; NRA, the row dimension of A; NCA, the column dimension of A; NAMAX, the maximum row dimension of A; IOKEY, the code of the type of operation that is to be done to A; IROW, the row to be modified; ICOL, the column to be modified.

IOKEY can contain values from three to eight, each value signifying the portion of the matrix to be modified. A three in IOKEY means that all of the matrix is to be modified by the percentage which is input in SMULT and stored in the variable S. A four in IOKEY means that the rows are to be modified, each by a separate value. The percent values are read by SMULT into the array S. The percent in element i of S is the percent by which row i of A is to be modified. A five in IOKEY means that the columns of A are to be modified, each by a separate value. The values for this operation are handled in the same way as for the rows. A six in IOKEY means scale a single row of the array A by the value read into S. A seven in IOKEY means scale a single column of A by the value read into S. An eight in IOKEY means scale a single element of A by the value read into S.

SMULT is called from an I/O routine because of the nature of the INFLATE command. The command card is read into the array KEY in

MASTER and since the subcommand is exactly the same as an I/O command, MASTER calls the proper I/O routine to decode the subcommand and then the I/O routine calls SMULT with the array referenced by the subcommand and the array dimensions as parameters. The values in IOKEY are set in MASTER.

If IOKEY is found to contain a three in SMULT, the variable S is read and if the program is in list mode, the value of S is printed. Then the entire matrix is multiplied by S + 1.

If IOKEY is found to contain a four, the values of the array are read and then the elements of row i of A are multiplied by $S_i + 1$, i = 1, 2, . . . , NRA. If the program is in list mode, the values of S are printed.

If IOKEY contains a five, the values of S are read and each element of column i of A is multiplied by $S_i + 1$, i = 1, 2, . . . , NCA. The values of S are printed unless in NO LIST mode.

If IOKEY contains a six, the single value of S is used and the elements in the row corresponding to the value of IROW are multiplied by S + 1. If IROW contains a number larger than NRA, the program enters recovery mode, a diagnostic is given, and the INFLATE is not performed.

If IOKEY contains a seven, the value of ICOL is checked against NCA. If ICOL is larger than NCA, the program enters recovery mode, a diagnostic is given, and the INFLATE is not performed. If ICOL is a legal value, the single value of S is read and the elements in the column corresponding to ICOL are multiplied by S + 1. The value of S is printed unless in NO LIST mode.

If IOKEY contains an eight, IROW is compared to NRA and ICOL is compared to NCA. If IROW is greater than NRA or if ICOL is greater than NCA ,the program enters recovery mode, a diagnostic is given and the INFLATE is not performed. If IROW and ICOL are legal values, then the value of S is read and A(IROW, ICOL) is multiplied by S + 1. S is printed when in LIST mode.

DATA TAPE MANIPULATION

All tape handling is done in SUBROUTINE INITIL through multiple entry points. While each entry point defines a logically independent routine, most of them use common sections of code, such as the copy and recopy routines beginning at statement number 1500.

The Data File Tapes are written in binary mode. Each file on the tape (with two exceptions) contains all of the variables which are used in the simulation and some file information grouped in 5 logical records. The first record in each file is a one-word integer file number which can have values from 1 through 99. (Format statements in MASTER and INITIL must be changed to accept any larger value.) The file number is used whenever referencing the file. The second record is 51 words long. The first word is the date when the file was written (by either an AUGMENT or UPDATE) in the form mm/dd/yy. The rest of the record is a 50-word Hollerith description of the file for documentation and identification purposes. This description is read from the 5 cards immediately following the file-number-card of the AUGMENT which created the file. The remaining three records contain the data blocks BOTH, KURT, and TERRY respectively.

Two of the files, as noted above, contain only one logical record--the file number. "Dummy file" number 0 is the first file on the tape. If the last data file is file number N, then dummy file K = - (N + 1) is the last file on the tape. These two dummy files are used by the routine to signal logical end-of-tape in either direction. Note that before the routine is exited, tape 25 is positioned at the beginning of a file (between the previous EOF mark and the file number), and KFIL is set to either the number of the file at which the tape is positioned or else to the previous file number plus 1.

In addition to the data file tape (which is assumed to be logical unit 25), the routines require 2 scratch units. These may be tapes, or they may be simulated on a drum, disk, etc. , but they will be referred to as tapes. Logical unit 24 is used to save the program's current matrices, since these storage areas are used as buffers for tape copying. Note that unit 24 is always kept at rewind point to avoid losing track of where the tape is. Unit 23 is used to make a copy of the data tape when editing (AUGMENT, DELETE, or UPDATE). When the editing is complete, 23 is copied back onto 25 to be saved. This unit is always rewound before final exit from the subroutine to avoid duplication of files on the next copy. If a copy of the data tape is to be made (user command Q25QCOPY), a complete copy (including dummy file zero) is written onto logical unit 20.

INITIL requires several service routines, most of which do tape handling operations. Integer function TIMEF is an MSU 3600 library routine which returns the calendar date (in the Hollerith form mm/dd/yy) when called with a parameter of 1. Subroutine SKIPFILE reads forward on the logical unit given as the parameter until it has passed an end-of-file mark. The tape is then positioned immediately after the EOF mark. Subroutine BACKFILE reads backwards on the logical unit given as its parameter until it has passed an end-of-file mark. The tape is then positioned immediately in front of the EOF mark. Calls are compiled to library routines by the 3600 FORTRAN instructions ENDFILE, REWIND, and BACKSPACE. ENDFILE writes an EOF mark on the unit number specified. REWIND causes the unit specified to be rewound. BACKSPACE causes the unit specified to back up one logical record. The statement IF (EOF, n) s_1, s_2 checks the last read operation on unit n. If an EOF mark was read, control transfers to s_1; otherwise control transfers to s_2.

Entry INITIL is called from MASTER for the command INITIALIZE FROM DATA FILE. Upon entry, the file number requested is in NFIL (common block BOTH.) NFIL is checked against KFIL to determine whether forward or backward searching is to be done. The search continues until (a) either of the dummy files is read, indicating that the specified file is not on the tape or (b) a file number is read which matches NFIL, in which case the matrices are read from the tape and KFIL is reset.

Entry UPDATE is called from MASTER for the command UPDATE DATA FILE. Upon entry, NFIL contains the file number requested. Since a file is to be rewritten and write-read sequences are not allowed, the entire tape must be copied (and edited) onto unit 23 and then copied back onto 25. Unit 25 is rewound, if necessary, and copying begins. As each new file is read, its number is checked against NFIL. If the number read is less than NFIL, copying continues. If the number read is greater than NFIL or if End-of-Tape, EOT, (a negative file number) is read, then the file requested is not on the tape, and a recovery procedure is entered. If the number read equals NFIL, the saved matrices are read from unit 24, written as the updated file, and copying continues to EOT. The files are then recopied onto unit 25, a message is printed, and the routine exists.

Entry DELETE is called from MASTER for the command DELETE

FROM DATA TAPE. Upon entry, NFIL contains the file number requested. Copying and searching is done as in the UPDATE routine except that if the file is found, it is skipped and not written on unit 23. After recopying and printing a message, the routine exists.

Entry AUGMNT is called from MASTER for the command AUGMENT DATA FILE. Upon entry, the file-number requested is in NFIL. If NFIL is positive, AUGMNT begins a search and copy operation as described for the UPDATA routine. If EOT is reached, the end of the tape is AUGMENTED. If a file is found with a number greater than NFIL, the file to be AUGMENTED is written onto unit 23, and the copy continues at the point where it was interrupted. If a file is found with a number equal to NFIL, the equivalence flag is set, NFIL is entered into the equivalence table, and a search for an empty spot is begun. (Note that this search is begun immediately if NFIL is equal to zero upon entry.) The search is performed as follows: NFIL is increased by one, the rest of the file is read from unit 25 and written onto 23, and the next file number is read. If this file number equals NFIL, the process is repeated. If the file number read is greater than NFIL,an empty spot has been found. If this is an equivalenced file, NFIL is entered into the equivalence table and a message is printed. The file to be AUGMENTED is written onto unit 23, and the copy continues at the point where it was interrupted. When the copy is completed, 23 is copied back onto 25, a message is printed, and the routine exists.

Entry COPY is called from MASTER for the command Q25QCOPY. Unit 25 is rewound, if necessary, and is copied completely onto unit 20. When EOT is reached, unit 20 is rewound, the saved matrices are restored, a message is printed, and the routine exists.

Entry NEWMT is called from MASTER for the command Q25QINIT. Tape 25 is rewound if necessary, and the two dummy files 0 and -1 are written. Note that this sequence essentially destroys any information which was on the tape. Note also that these dummy files are necessary for proper operation of the routines.

Entry LIST is called from MASTER for the command LIST DATA TAPE. Tape 25 is rewound if necessary, and the tape is read to EOT. For each file, the file number, the date written, and the Hollerith description are printed.

*****CAUTION TO THE USER

Note that the data tape on unit 25 is quite vulnerable, since an abnormal job termination (time limit exceeded, for instance) while it is being rewritten could leave it incomplete and therefore unusable. Although there is no fool-proof way to keep the tape intact, there are several ways to ensure that the system crashes softly. One method is to periodically write a back-up tape (Q25QCOPY) so that even if the main tape is destroyed, the data it contained will still be available. A more convenient way is to equip unit 23 to a saved tape, thus keeping the backup tape completely up-to-date. Whenever a recopy operation is started, the message "RECOPY HAS BEGUN" is printed. Immediately after this message is printed, unit 25 is written. If the recopy is completed, a message is printed confirming the operation. By observing which messages have been printed, one can determine whether tape 23 or tape 25 is intact.

NOTE:

Two ways to aid in "crashing softly" are implemented in a later version of MSUSIM2. Routine INITIL was slightly modified to operate as a 2-tape system, where the user equips tapes to LUN 23 and 25, and the routine itself decides which of the two is most recent by comparing edition numbers on each of the tapes. This method eliminates the time-consuming recopy operation and is fail-safe since a new edition number is not written until after an editing request has been successfully completed. A second feature of this version is a pair of commands (PUNCH OUT and READ PUNCH) which allow a user to punch a whole data file (in internal form) onto cards and read from cards. This feature allows a user who doesn't have access to tapes to operate completely in punched card mode.

4:5.3.3 Engineering College Data File

In order to make practical use of MSUSIM2 a realistic data file is required. Results from STUVEC and CLASCARD runs were utilized but not all of the data which can be effectively utilized by MSUSIM2 is readily available from central University sources. Through the cooperation of the College of Engineering it has been possible to develop a complete Engineering College Data File. However, because of differences in accounting practices followed in various sectors of the University, some modification of the data is necessary to provide a consistent data file. The "raw" and "modified" versions of the data base have been prepared as described next.

The RAW ENGINEERING DATA FILE (FILE 04 - AUGUST 1968) contains actual data for the year 1967. There are 8 fields, 5 levels, and 1 rank.

The fields are:

1. Chemical Engineering (CHE)
2. Civil Engineering (CE)
3. Mechanical Engineering (ME)
4. General Engineering (EIS or GEN)
5. Electrical Engineering and Systems Science (EE/SYS)
6. Computer Science (CPS)
7. Metallurgy, Mechanics, and Material Science (MMM)
8. Other (This includes all fields outside of the College of Engineering.)

The levels are:

1. Freshmen and special
2. Sophomore

3. Juniors
4. Seniors and Vet. Med. fourth and fifth year
5. Graduate Students

The data was obtained as follows:

The ENROLLMENT was taken from "NEXT YEARS ENROLLMENT", from STUVEC for Fall of 1967. A correction had to be made to move SYS students from CPS-SYS on STUVEC to EE/SYS for MSUSIM. The number of SYS students was taken from "SUMMARY OF ENGINEERING STUDENTS, FALL TERM 1967, COLLEGE OF ENGINEERING."

The figures for PERCENT BREAKDOWN OF TOTAL NEW STUDENTS were taken from the "NEW STU" column of the percentage breakdown table from STUVEC for Fall of 1967.

The NUMBER OF TOTAL NEW STUDENTS came from "TOTAL STUDENTS ENTERING" from STUVEC for Fall of 1967.

The STUDENT TRANSITION TABLE came from "STUDENT TRANSITION TABLE-PERCENTAGE DATA" from STUVEC for Fall of 1967.

The STUDENT GRADUATION PERCENT TABLE came from the "GRADUATED" row (for undergraduates) and the "GRAD STU ABS" row (for graduate students) of the STUDENT-TRANSITION TABLE-PERCENTAGE DATA from STUVEC for Fall of 1967.

The DEMAND FOR CREDIT HOURS table was taken from the "CREDITS PER STUDENT" table (C matrix) from CLASCARD run number 318131. No adjustment was made to correct for the fact that CLASCARD groups CPS and SYS while MSUSIM groups EE and SYS. A correction of this type was made in a revised engineering data file.

The DEMAND FOR TEACHING ASSISTANTS in each field was found from the application for assistantship forms obtained from the office of Dean of the College of Engineering (the entries for field "OTHER" were left blank). The number of undergraduate credits (it was assumed that teaching assistants teach only undergraduate courses) was taken from the "CREDIT DISTRIBUTION MATRIX" from CLASCARD run number 176241. It was assumed that the demand for teaching assistants was evenly spread over all levels of courses offered in any given field. It was also assumed that all teaching assistants are graduate students. Therefore, for each field the number of teaching assistants was divided by the number of undergraduate credit hours taken in that field. This number was then entered in the graduate (level 5) row of the given field in every column for that field corresponding to an undergraduate level in which that field offered courses.

The next group of entries deals with faculty effort. The breakdown of faculty effort was taken from TABLE I,"DEPARTMENT EXPENDITURES BY FUNCTIONS (A), FALL 1967". It was assumed that FTEs were proportional to expenditures. The expenditures for a given function were divided by the total expenditure for the department (field). These fractions are referred to as "fraction of total FTE for . . . " and will be the starting point for obtaining the next set of tables. The figures pertaining to the number of faculty in each field came from the office of the Dean of Engineering.

The fraction of total FTE EFFORT FOR UNDERGRADUATE INSTRUCTION for each field was multiplied by the number of faculty in that field to give the number of FTEs spent by each field on undergraduate instruction. The number of FTEs spent by each field was then divided by the number of undergraduate student credit hours taken in that field to give FTE/student credit hour spent by each field for undergraduate instruction. In entering these figures it was assumed that faculty of a given field teaches only courses in that field. It was further assumed that for any given field the FTE/student credit hour was constant over all undergraduate levels.

Thus, for field 1 the effort spent was 0.004126 FTE/student credit. This figure was entered in row 1 (field 1, rank 1), columns 1,2,3,4 (field 1, rank 1,2,3, and 4). No data was entered for field 8.

The EFFORT FOR GRADUATE INSTRUCTION table was set up similar to EFFORT FOR GRADUATE INSTRUCTION. Fraction effort for graduate instruction (800 and 900 level instruction) and number of graduate credit hours were used in place of the corresponding numbers for undergraduates. It was assumed that faculty of a given field instructs only courses in that field. Since, for this data, level 5 is the only graduate level and since there is only one rank of faculty, the number of FTE/student credit hour for field I is entered only in the row for field I rank 1, the column for field I level 5. No data was entered for field 8.

The EFFORT FOR UNDERGRADUATE ADVISING was estimated by the Engineering Student Affairs Office that the average student received 40% of his undergraduate advising from faculty in his field as a sophomore, 30% as a junior, and 30% as a senior. To allow for the different number of students at different levels, these figures were corrected for each field as follows. Student advising equivalents (SAE) were found by the formula: SAE = .40 x (number of sophomores in given field) + .30 x (number of juniors) + .30 x (number of seniors) x (number of faculty in field) x $(\frac{.40}{\text{SAE}})$ = FTE/student for sophomores of the given field. (Let Y = $\frac{.40 \times \text{No. of sophomores}}{\text{SAE}}$ = fraction of total FTE for advising sophomores, then (Y) x (number of faculty in field) = FTE for advising sophomores, Y/number of sophomores = FTE/student for advising sophomores in the given field.) Similarly, (number of faculty in field) x $(\frac{.30}{\text{SAE's}})$ = FTE/student for advising juniors and for advising seniors. It was assumed that faculty of a given field advise only students in that field and that only sophomores, juniors, and seniors receive undergraduate advising from faculty in their field.

No data were entered for field 8.

For each field the fraction of total FTE EFFORT FOR GRADUATE ADVISING (MS advising and Ph. D. advising) was multiplied by the number of faculty in each field to get FTE for graduate advising for each field. These numbers are divided by the number of graduate students in each field to get FTE/student for graduate advising for each field. It is assumed that faculty of a given field give graduate advising only to graduate students in that field.

EFFORT FOR THESIS SUPERVISION table was determined in a manner similar to that described for EFFORT FOR GRADUATE ADVISING. Fraction of total FTE for thesis supervision (MS thesis and Ph. D. thesis) was used rather than the corresponding figures for graduate advising. The same assumptions were made.

The figures for:

EFFORT FOR COMMITTEE WORK,

EFFORT FOR UNDERGRADUATE COURSE DEVELOPMENT,

EFFORT FOR GRADUATE COURSE DEVELOPMENT,
EFFORT FOR PUBLIC SERVICE,
EFFORT FOR SEMINARS AND MEETINGS,
EFFORT FOR ADMINISTRATION,
are the "fraction of total FTE for . . ." as described above.

For EFFORT FOR COMMITTEE WORK, the fraction of total FTE for department committees, college committees, and university committees were added together.

The FACULTY SALARY SCALE was obtained by taking an average, weighted by number of faculty of each rank, of the average salary of each rank, for each field. These salary figures came from the office of the Dean of Engineering.

The ASSISTANTSHIP SALARY SCALE, a nonweighted average of a master's assistantship and a doctoral assistantship,was taken. The figures for these assistantships came from the office of the Dean of Engineering. It was assumed that amounts of assistantships do not vary over the different fields.

The COST OF SECRETARIES, COST OF LABOR, COST OF EQUIPMENT, and COST OF SUPPLIES AND SERVICES were taken directly from the actual operating accounts assigned to each department, except that the salary account includes all faculty and staff salary as well as the secretarial salaries. Thus, this division of funds represents the way the university actually operates. No entries were made for field 8.

The FRACTION COST OF x FOR y, where

x = SECRETARIES, LABOR, EQUIPMENT, and SUPPLIES AND SERVICES y = UNDERGRADS, GRADS, and THESIS AND RESEARCH were given in a report to the Dean of Engineering from the Department Chairmen. In combining EE and SYS a weighted average of the fraction breakdowns of these two departments was taken.

The amount of sponsored RESEARCH GRANTS (in thousands of dollars) held by faculty in each field was obtained from the office of the Division of Engineering Research. A change was made to correct for an inconsistency in data. CPS spent .572314 FTE on sponsored research, but were not shown to have received any research grants. It was decided that this was probably due to CPS faculty doing research under SYS grants. Therefore, the FTE devoted to sponsored research by CPS and EE/SYS were added together and the sum divided into the research grants for EE/SYS to get a common FTE/$1000 outside research grants figure. This figure was then divided into the FTE devoted to research by EE/SYS and by CPS, thus dividing the EE/SYS research grants between CPS and EE/SYS on a basis of FTE spent by each of these fields.

To get EFFORT FOR RESEARCH for each field, the amount of research grants, in thousands of dollars, (see above) was divided by the FTE spent by that field for sponsored research. The number of FTE was obtained by multiplying the fraction of total effort for sponsored research for each field by the number of faculty in that field. The effort spent by CPS and EE/SYS was computed jointly (see RESEARCH GRANTS) by adding FTE spent by CPS to FTE spent by EE/SYS and dividing this sum into the research grants for EE/SYS. The resulting figure was then entered for both CPS and EE/SYS.

The DEMAND FOR RESEARCH ASSISTANTS in each field was divided by the research grants, in thousands of dollars, held by that field. The number of research assistants was obtained by counting the number of approved requests for research assistantships on file in the office of the Dean of Engineering.

The Modified Engineering Data File (File 05 - August 1968) differs from the raw engineering data file in only two tables. The first change is in the DEMAND FOR CREDIT HOURS table, which is altered to reflect the fact that in calculating credits per student, the CLASCARD program uses the number of students in each field and level with CPS and SYS taken together, whereas the ENROLLMENT vector input to MSUSIM2 has had the enrollment corrected by moving some students from field 6 to field 5 (i. e., SYS students to the EE/SYS field). Since the credit demand characteristics of SYS students are not (at present) differentiable from those of EE or CPS students, the only correction possible is the adjustment of DEMAND FOR CREDIT HOURS table so that the total credits demanded (the product of the table and the enrollment) is the same as it is before the SYS students are moved from field 6 to field 5. This is accomplished by multiplying each relevant column by the factor:

$\dfrac{\text{students in the field-level with CPS/SYS grouped}}{\text{students in the field-level with EE/SYS grouped}}$. There were no SYS freshmen or graduate students, but the enrollments for the other three levels (and the necessary INFLATE quantities) are:

	field 5 level 2	field 5 level 3	field 5 level 4	field 6 level 2	field 6 level 3	field 6 level 4
CPS/SYS grouped	112	117	104	36	32	11
EE/SYS grouped	124	120	107	24	29	8

INFLATE COLUMNS 22(5,2) $\frac{112}{124}-1$ = -.09677420
23(5,3) $\frac{117}{120}-1$ = -.02500000
24(5,4) $\frac{104}{107}-1$ = -.02803739
27(6,2) $\frac{36}{24}-1$ = -.50000000
28(6,3) $\frac{32}{29}-1$ = -.10344270
29(6,4) $\frac{11}{8}-1$ = -.37500000

The other modification in the modified engineering data is a correction for the short-term transient effects which appeared in the STUDENT TRANSITION TABLE for 1966-67 because of the creation of the CPS major. The transitions within CPS and from some fields into CPS were replaced with the corresponding transitions within and into M.E., so that the table might reasonably be used for longer-range projections. The changes made in the table are listed below:

	Old val.	New val.
6-1 to 6-2		.18
6-2 to 6-2		.03
6-2 to 6-3	.50	.41
6-2 to 6-4		.01
6-3 to 6-3		.01
6-3 to 6-4	.50	.59
6-4 to 6-4		.17
6-4 to 6-5		.05
6-5 to 6-5		.58

Also the following changes were made.

4-1 to 6-1		.01
4-1 to 6-2	.04	.07

4:5.3.4 Listing and Sample Run of MSUSIM2

A documented listing of MSUSIM2 and an example demonstrating a typical simulation run is available under a separate binding.

Part 5

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5:2 Project Record of Publications and/or Presentations

5:2 Project Record of Publications and/or Presentations

During the period of support of contract C-396 initiated October 1964 and contract C-518 initiated July 1, 1966, the several papers listed below were presented at conferences, symposiums and workshops. In addition, more than 500 copies of papers and previous reports of the project have been sent out in response to written requests, and approximately eight visits were made to the Michigan State campus for consultation.

1. "A Systems Approach to Higher Education," Workshop held at Michigan State University, Under support of contract C-396, 40 attendees, June 2 and 3, 1966.
2. H. E. Koenig and M. Keeney, "A Prototype Planning and Resource Allocation Program for Higher Education," Operations Research Society of America, Durham, North Carolina, October, 1966.
3. H. E. Koenig, "State-Space Models of Educational Institutions," OECD, Paris, France, January, 1967. Published in Proceedings.
4. R. Zemach, Presentation at IEEE workshop on "Performance Measurement and Modeling of Educational Systems," New York City, March 22, 1967.
5. H. E. Koenig, "Measuring Cost and Effectiveness of the Large Information System," Pacesetter Address, University of New Mexico, April, 1967. Published in Proceedings.
6. R. Zemach, "State-Space Models for Educational Institutions, "IEEE Systems Science and Cybernetics Conference, Boston, Mass., October 12, 1967.
7. H. E. Koenig and M. Keeney, "A Prototype Planning and Resource Allocation Program for Higher Education," Symposium on Operations Analysis of Education, Washington, D. C., November, 1967. Published in Proceedings.
8. H. E. Koenig, "Theory of Interconnected Systems with Applications in Physical, Industrial and Socio-Economic Processes," Oklahoma State University - Engineering Lecture, December, 1967.
9. M. G. Keeney, Seminar presentation, Ontario Institute for Studies in Education, Toronto, Canada, December, 1967.
10. M. G. Keeney, One day of a four-part seminar series for top management of Argonne National Laboratory, Argonne, Illinois, January 16, 1968.

11. R. Zemach, "A State-Space Model for Resource Allocation in Higher Education," IEEE Transactions on Systems Science and Cybernetics, Vol. SSC-4, No. 2, July, 1968 (Same paper as (6)).

12. M. G. Keeney, Panel - University Management Information System Session Urban and Regional Information Systems Association Annual Conference, St. Louis, Missouri, September 5-7, 1968.

Part 6

APPENDICES

6:1 Systems Analysis and Planning in University Administration

Prepared by

H. E. Koenig
M. G Keeney
R. Zemach

SYSTEMS ANALYSIS AND PLANNING IN UNIVERSITY ADMINISTRATION

Prepared for:

Advisory Committee to Project C-518,
"A Systems Approach to Higher Education"
September 14, 1967

Prepared by:

H. E. Koenig
M. G. Keeney
R. Zemach

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INTRODUCTION

Within the last few years, considerable effort has been devoted to computer implemented procedures for dealing with the problems of planning and resource allocation in institutions of higher education. The purpose of these efforts has been to analyze and "optimize," in some sense, the operation of the institution.

The Systems Analysis and Planning Program described here provides the "logic" of an information processing program to aid university administrators in the over-all allocation of resources to achieve their stated objectives. The resources of the university are described in terms of measurable quantities of personnel, space, and equipment, as well as the associated budget required to obtain them at the price levels imposed by the economic environment.

No attempt is made to define the academic goals of higher education nor to determine optimal allocation policies nor to design decision-making procedures as such. Instead, the purpose is to provide a rational basis for evaluating alternate allocation policies under the assumption that the university has varied and perhaps conflicting goals defined by those entrusted with decision-making responsibilities.

In comparing these alternate allocation policies, consideration must be given both to the feasibility of achieving a given set of the desired goals and to the cost of implementation. Will additional personnel be required? Will space be diverted from some other use? And finally, what will be the total budgetary requirements?

No matter how limited the goal, each policy decision affects the operation of the entire university, and the related cost can only be determined by taking into account the total pattern of resource requirements.

The effect of changes in the social and economic environment must also be accounted for. In addition, since the university is a dynamic institution, changing through time, the time-horizon for achieving objectives must be a factor in policy decisions. For all these reasons, computer programs to process data and produce information to aid in resource allocation and other administrative decisions must be based on a description of the university as a total, dynamic, interrelated system.

To illustrate this interdependence of decisions and their temporal nature, suppose it is decided that the graduate program in a given area should be expanded. Recognizing that the enrollment at the graduate level depends to a large extent on the availability of graduate assistantships, the decision is made to further the graduate program by offering more graduate assistantships in particular fields of study. Clearly, there will be an increased demand for graduate level courses and later for more dissertation guidance. But how much and at what point in time will these changes occur? Should the graduate assistants be used in undergraduate teaching, thereby releasing more faculty for graduate programs? Or would it be better to support them by increased sponsored research? How will each of these alternatives affect the type of faculty talent required? The decision depends also on whether a clear policy exists on the use of graduate assistants in undergraduate teaching.

Suppose a seemingly unrelated decision is made at the same time, or perhaps a year or two later, to increase the number of undergraduates in the College of Engineering. Will more faculty be needed, or will graduate assistants be used in the expanded teaching program, and if so, must the graduate program also be expanded? What demands will the engineering students impose on the mathematics, physics, and chemistry departments, and how will these demands be satisfied? How will the various area budgets be altered in the face of one or both changes?

In a related context, if a decision is made to introduce a new educational program which will attract large numbers of new students within a few years, particular types of demands will be imposed on other academic departments, and these demands must also be satisfied. The effects must be anticipated well in advance.

Clearly decisions of the type cited above cannot be made in isolation; all changes in the operation of the university are inevitably related. The computer implementation of a system analysis and planning model, of the type described here, provides the administrator with the capability of examining these and other relationships and of utilizing all available information in the decision-making process.

The System Method

Computer programs used to process data and provide information to aid in resource allocation must be based on a detailed description of the university as a dynamic, interconnected system. Further, since computer programs process data and produce information in quantitative form, the description must be mathematical. A mathematical description of the operation of a system is referred to as a system model.

The model described here is a mathematical description of the way the university utilizes its resources in production. The resources of the university are described, broadly, as personnel, space, and equipment. The products are identified as developed manpower, research, and public or technical services. The model itself consists of sets of equations which describe the relationship of resources to production and, based on these, the associated cost of production.

These equations are similar in form to those used by engineers to describe mathematically the behavior of a physical system as it operates over successive periods of time. Consequently, it is possible to explore the application of all aspects of system theory to the university system. In particular, certain variables of any system are identified as control factors. These variables have two properties: they are at least partly under the direct or indirect control of those responsible for operating the system, and their manipulation affects the future state or position of the system.

The control problem, in its most general context, is: for some well-defined goal, determine the sequence of operating policies and the controls required to achieve this goal in an optimum manner. When applied to a system of higher education, control theory addresses itself to such questions as: "What set of allocations on limited resources will result in minimum cost of education given an acceptable level of quality?" or 'What sequence of operating policies and controls will produce the desired type of educated manpower at minimum cost over a period of x years?"

Formal application of control theory to management and planning for a university is particularly challenging. The goals must be determined taking into account both the social demands of the population and the economic and cultural needs and resources of the local, national, or world community; quality of education must be defined in measurable terms. In addition, a variety of exogenous factors affect the system, many of them unmeasurable and, indeed, often unperceived. It seems unlikely that mathematically-described control policies could be, or should be, applied to a social system as complex as a modern university, and no attempt is being made to develop one. Rather the system model, or mathematical description, is used as the "logic" of computer programs that process statistical data on the university in such a way that the consequences of alternate policies in the allocation of resources and the implementation of designated controls can be evaluated over time.

The mathematical description under development has provisions for including descriptive equations for control factors, and the nature of some of them are being identified explicitly. It is certainly well-recognized, for example, that the availability of scholarships, fellowships, and assistantships influences the composition of the student body. These financial aids, therefore, constitute a control factor in the form sense and are included in the mathematical description. A detailed study of the specific nature of the influence of financial aids is being pursued. As other controlling factors are identified and quantified, their influence can readily be incorporated in the mathematical description in a similar manner.

History of the Project

In 1964, a research program was initiated under the support of the National Science Foundation to determine, first, whether it was possible to develop a valid mathematical description, or system model, of the university, and, second, whether usable and effective information processing programs based on this model could be implemented on a computer to answer important questions concerning allocation policies. The theoretical structure of such a model was developed in the early stages of the project and refined more recently. With the cooperation of the Office of Institutional

Research considerable attention has already been devoted to the problems of providing an adequate data base from which to work.

The project now stands on the threshhold of practical application of the system method in decision-making. The last steps towards the use of the model cannot be taken by system specialists and computer scientists alone. It has become increasingly important for the university administration to become acquainted with the objectives of the project, its potentials and limitations and to provide suggestions for the direction of future efforts.

A Mathematical Description of the University

If the preceding discussion has left the impression that the system model is as complicated and difficult to understand as the institution it describes and that its computer programs will produce indigestible quantities of information, then two aspects of the project must be emphasized. In accordance with standard engineering practices, the total model, or description, is composed of several sectors or components. Each sector is related to a specific aspect of operation of the university. Equations are associated with each sector to describe the relationship among the services produced, the resources required, and the demands imposed on other sectors of the university. The sector descriptions are simple in form and may be studied independently. The total model is formed by describing the constraints, or restrictions, which the different sectors impose on one another.

In addition, the computer programs are being developed to answer specific questions. The computer will assume the task of digesting data related to all phases of university operation and producing only the information requested.

In the following paragraphs, the sectors of the model are described followed by an example which shows in simplified form the information contained in and produced by the mathematical descriptions. The sectors or "building blocks" of the model are summarized schematically in Figure 1.

The Student Sector [Figure 1 (a)]

The internal state, or condition, of the university at any particular time is described in terms of the distribution of students among the various areas of education and levels of study and the respective average accumulated costs of education to that point in time. The equations of the student sector describe the dependence of the enrollment distribution on the previous year's distribution, its dependence on the enrollment choices of new students, and its dependence on available graduate assistantships, fellowships, scholarships, and other financial aids. The form of the equations also allows the inclusion of other factors which influence student enrollment, if they can be described quantitatively.

The student sector of the model also describes the number and educational status of the students who leave the university--their fields of study, matriculation levels and the average "cost" or investment accumulated to the time of departure.

In all these descriptions, it is possible to separate out special groups of students, according to any item contained in student record files. Programs may be written to produce information on married students alone, on Michigan residents alone, and on students distinguished by grade-point average. Present programs allow any desired groupings of departments and levels of study.

Academic Production [Figure 1 (b)]

The distribution of students generates a particular pattern of demand for course-credit-hours and research-teaching associated with dissertation research. These may be referred to as academic services. Other academic services, such as sponsored research, continuing education, or special programs, are similarly demanded by the community outside the university. The equations of a sector of the model called Academic Production describe the relationship between the quantities of academic services produced and the quantities of faculty effort, graduate assistant effort, and environmental facilities, such as classrooms, laboratories, and technological equipment, required to produce the academic services.

The description of this sector includes the cost of services produced based on the costs of resources required. These costs determine the cost of education, referred to in the student sector as well as the cost of sponsored research and other services.

Non-academic Production [Figure 1 (c)]

Services such as housing, registration, counseling, or medical service must also be produced to satisfy student demands. The equations of the sector known as Non-academic Production again indicate the quantities of effort and facilities required to meet these demands as well as their cost.

Personnel and Physical Facilities [Figure 1 (d) and (e)]

The resources required by the Academic and Non-academic Production sectors--various types of personnel effort and various types of space or environmental facilities--are in turn produced by sectors of university operation referred to in the model as Personnel and Physical Facilities. To produce faculty teaching effort, for example, the university must utilize not only the "labor" of the academic employees themselves but also the labor of secretaries and other supporting staff and the office space and other facilities required to maintain the academic staff on the campus. Equations of the Personnel sector indicate the quantity of each of these resources used to produce a given number of units of effort, of all types, required by the Production sectors.

Similarly, classroom facilities used in teaching require not only the building space itself but also the efforts of a maintenance staff. The use of a closed-circuit TV system in teaching requires the efforts of operators and technicians. The equations of the Physical Facilities sector show the required amount of space, equipment, and staff effort required to produce the units of environmental facilities utilized by the production sectors.

Information giving the costs of resources required by the production sectors is also included. These costs are based on total requirements. This means, for example, that the cost of a unit of faculty service is computed on the basis of average faculty salary, average cost of office space and equipment, cost of a percentage of supporting secretarial effort, and other secondary costs related to academic personnel. Similarly, the average cost of classroom units will include maintenance and operation.

If capital investment costs can be allocated on the basis of use of facilities, these costs may be incorporated into the cost-of-production information.

Administrative Control

Units of effort and facilities are also required by the sector identified as Administrative Control. However, the administrative policy decisions produced as "output" by this sector are not described in quantitative units. Rather, the policy decisions produced by the Administrative Control sector are viewed as allocating the resources. This is achieved in the model by altering the input-output relationship of each sector, i.e., by setting policy as to how the resources available to each production sector are allocated to meet its production requirements. A decision to change policies of resource allocation becomes, in the model, a change in the equations themselves.

The System Model [Figure 2]

Each of the sector models can be used as a basis of limited analysis and planning directed at the specific sector to which it refers, or they can be combined as described later to establish a model of the entire system.

The total system model consists of sets of equations indicating the resources of personnel, space and equipment required to meet the demands imposed by the student body and the outside community. However, since these equations are derived from the equations of the separate sectors, the resource allocation policies implicit in these relations are composites of the policies identified for the production sectors.

When the independent descriptions of the sectors are combined, constraints are imposed on the values that the related variables may assume. The credit hours produced by Academic Production are those demanded by the Student sector. The building space used in connection with Physical Facilities is equal to that needed to produce the classroom, laboratory, office, and other space demanded as shown pictorially in Figure 2. The use of personnel is similarly constrained. Such a model differs from traditional economic models in that all resources are considered as scarce, when compared to demands, and demands are regarded as obligations which must be met. The "inputs" of personnel and physical facilities are considered to be totally utilized in each time period and are therefore regarded as the resources required to meet production, under existing operating policies.

One of the most interesting constraints included in the total system description concerns the composition of the student body. The number of graduate assistants employed by the university is related to the undergraduate student enrollment distribution, through the demand for undergraduate course credit hours. On the other hand, the enrollment distribution, at least in the graduate levels, depends in part on the availability of graduate assistantships. Therefore, the equations of the model describe a circular relationship, or loop, associated with the employment of graduate assistants. Questions concerning allocation of resources and costs to various student programs can only be answered by descriptions which account for this circular relationship.

Simulation

If the model is valid and the equations developed do indeed describe the policies followed in utilizing resources to meet the various production requirements imposed by the student body, the model can be used to simulate changes in allocation policies and other conditions. This means that an administrator can experiment with changes in the value of some of the numbers in the equations to see how the production or the required resources will change. He may simulate changes in the composition of the student body, in programs being offered, in class size, in teaching methods, in salary scales, or in any factors which are quantitatively described in the model.

Practical use of the model in this way motivates the second phase of the project. Depending on the types of problems to be approached, a variety of computer programs may be developed, based on the theoretical model. Each program allows experimentation with particular types of variables and policies and yields particular information. It is unlikely that one decision will require consideration of all areas of activity. However, a contemplated change in operating policy in one area may well have unexpected ramifications in seemingly unrelated areas. In addition, administrators with different responsibilities may have different goals which they seek to achieve. By basing selective programs on a total system model, interaction of various changes of policy may be examined.

The initial values of the numbers in the equations are based on actual data which in effect identify the allocation policies implicit in the current operation of the university. However, the model can be updated periodically in two ways to respond to changes in the institution. First of all, since the total system model is composed of models of separate sectors of activity, the theoretical model itself can be modified by addition, aggregation, or redefinition of its sectors and variables within the overall mathematical model. Secondly, and more important, the numbers in the equations may be re-evaluated periodically from current data, thus keeping the model valid as patterns of allocation change. In fact, inspection of the time-change in the value of these variables, computed over several time periods, may point out important changes that are taking place in the operation of the university which are not otherwise evident.

Example: A System Description

The mathematical structure of the model, in completely general terms, has been presented in (1), (2), and (3). The purpose here is to present examples of the implementation and use of the model, using only two areas of study and two levels and using hypothetical values for the numbers which would normally be derived from university data files. In the theoretical model, each sector is described by equations relating resources to production. In this example, however, the information contained in the equations are presented in the form of tables. The interpretation and use of numbers in the tables are described. For those who wish to refer to the theoretical studies, the corresponding equation on which each table is based is included.

Assume we are now in a time period (term, school year, etc.) which will be referred to as Period 1 and that we wish to make an analysis of the present operation of the university. Starting with actual data from university files (assumed values in this example), sets of tables are developed which represent either resource allocation policies, behavioral parameters of the student body, resources, products, costs, or controls.

Until enough operating data is available to prove otherwise, it has been assumed that all input-output relations are simple ratios. Therefore, the entries in many of the tables will be of the type familiar to university administrators--such as units of faculty effort per student credit hour or average distribution of course credits for students in each field and level. Other tables describe the behavioral patterns of student transitions from one year to the next or student response to financial aids.

The mathematical techniques involved in the use of the model cannot be described in detail here. It is sufficient to say that the effect is to combine the information contained in several tables and to compute the flows and unit costs at various points in the system. Only the results are described.

Specific implementations of the general model take a variety of forms, depending on the level of detail at which data are available, on the level of detail required in the answers, on the number of sectors of the university that interact in the particular study, on the items that are of interest as input and output, and on the allocation policies and other variables to be altered in the study. The examples following are typical of the studies that can be made and the information gained therefrom.

In these examples, two fields of study are represented, e. g., Humanities (H) and Science (S) and two levels of study, say undergraduate (u) and graduate (g). Thus four "categories" of students are described:

Category	Field-level	
1	H	u
2	H	g
3	S	u
4	S	g

Student Transitions

The Student sector of the model expresses the change in enrollment from term to term as students enter, progress through, and leave the system.

It is assumed that we are in period 1, and therefore data are available on enrollments during the previous period, period 0, on the numbers of students who left the university from each category at the end of period 0, and on the numbers of new students who entered at the beginning of period 1. Table 1 summarizes the information on enrollment transition which can be developed. from these data.

Table 1 (a) and 1 (b) give the enrollment distributions for period 0 and period 1 respectively. A portion of the students enrolled in period 0 remain in school, though frequently in different categories. The remainder leave the system, through graduation as well as for other reasons, and their distribution is given in Table 1 (e). At the beginning of period 1, a total of 500 new students enter the system and are distributed over the categories as indicated by Table 1 (d).

The transition pattern of those students enrolled for both periods 0 and 1 is represented in the student transition table, Table 1 (c). A typical entry in the transition table is the percentage of students in the category indicated by the column heading during period 0 who are in the category indicated by the row heading during period 1. Thus, the transition table indicates that of the 500 students who were Humanities undergraduates during period 0, 57% remained in that category, 6% advanced to graduate status, 17% became Science undergraduates, and 5% entered the graduate program in Science. Table 1 (e) accounts for the remaining 15%, who left the university. The table thus accounts for all students who were in the university during period 0.

The table similarly accounts for all students enrolled during the present time, period 1. The transition table indicates that the 1010 students currently enrolled as Science undergraduates consist of 17% of the former Humanities undergraduates while 62% were previously enrolled in the Science program. The remainder of the Science undergraduates consists of 305 new students, or 61% of the new enrollment.

Although this example is hypothetical, it is an indication of the progress of the project that computer programs have been written which produce all the information exhibited in Table 1, based on Michigan State University student enrollment data files. These programs allow the user to choose any aggregation of fields and levels of study which would be meaningful for the questions he needs answered. Tables can be produced for any pair of terms or years since Fall 1963.

Factors Which Influence Transitions

For some purposes, the description of enrollment distribution changes given above might be adequate, but for other purposes it is not sufficiently detailed. Various factors influence the movement of students through the system, and as they are identified and measured, they can be represented in the model. They are accounted for by separating Table 1 (c) (student transitions) and 1 (d) (new entries) into component tables representing the transition and new enrollment which can be attributed to the influence of these factors. If these factors can be controlled by the university administration, they become controls of the system.

For example, suppose a portion of the student enrollment is influenced by financial aids such as assistantships, fellowships, and scholarships. The first step in obtaining a mathematical description of the influence of financial aids is the breakdown of Table 1, as shown in Table 2. The students in the university during period 1 are now accounted for in three parts. Table 2 (a) records the enrollment transition for those students who remain in the university or enter the university, independent of financial assistance. Table 2 (b) represents percentages of students who remain or enter because of assistantships, and Table 2 (c) attributes part of the enrollment to scholarships and fellowships. These data refer to the extent of influence of the financial aids on student decisions rather than simply to the question of whether or not the student is receiving aid. Those students who are receiving financial aid but who would have remained in school, or entered, without the aid are included in Table 1 (a). Again, students who are not receiving aid directly may be influenced by the existence of financial aids. For example, an undergraduate in science may remain in school in anticipation of assistantships available for later graduate study. His decision is recorded in Table 2 (b).

Table 1 (c) recorded the fact that of 200 students enrolled in the Science graduate program during period 0, 40% continued during period 1, while 10% became graduate students in humanities. Table 2 (a) provides the information that, independent of the influence of financial aids, 20% continued in science and 2% in humanities. Table 2 (b) and 2 (c) indicate that of the other 20% remaining in science, 9% can be accounted for by the influence of graduate assistantships and 11% by the influence of fellowships. Similarly, 5% of the science graduate students transferred to humanities because of the availability of assistantships and 3% because of fellowships.

The rest of the 211 Science graduate students enrolled during period 1 are new students, comprising 8% of the new enrollment. Table 2 shows that 4% of the new students entered graduate science because of assistantships and 2% because of fellowships. The remaining 2% were not influenced by financial aids.

In the same way, Table 2 accounts for the influence of financial aid in each category of enrollment and indicates an "adjusted" enrollment distribution for period 1, if all these financial aids were removed.

Assuming that the actual numbers of assistantships, scholarships, and fellowships that are given during period 1 can be obtained from university files, then the student enrollment transition can be expressed as in Table 3. This table indicates the dependence of student enrollment on the amount of financial aid offered. Financial aid has been suggested as an example of a control, but a similar description is necessary to analyze the influence of any variable on enrollment distribution.

In Table 3, it is assumed that 250 assistantships and 143 scholarships and fellowships have been used to retain and attract students. The numbers entered in Table 3 are the number of students attracted by the assistance for each unit of assistance offered. For example, for each assistantship offered, on the average, .22 students are retained in undergraduate humanities from the previous period, and .02 new students are attracted to undergraduate humanities. For each assistantship, a total of .92 students are retained in all categories, and .18 new students are attracted. This checks with Table 2, which shows that a total of 230 students were persuaded to remain in school by the 250 assistantships offered, and 45 were persuaded to enter. Thus one assistantship is responsible for the presence of 1.1 students in the system.

If the financial aids are effective as shown in this model, then one could ask what would happen if the number of assistantships were changed. Suppose, for example, that no assistantships had been offered during period 1, though the number of fellowships and scholarships remained the same. From Table 2, the following enrollment distribution can be computed:

Humanities - undergraduate	470
Humanities - graduate	78
Science - undergraduate	905
Science - graduate	151

The total enrollment would be 1604 in the absence of assistantships, compared with an enrollment of 1879 with 250 assistantships given. At the same time, only 455 new students would enter, and the total who left the system at the end of period 0 would be 696, including both the 421 who did leave and 275 who would have left if assistantships had not been available.

Table 4 shows how the same information on the influence of financial aids may be exhibited in greater detail. Here, it is recognized that assistantships or fellowships or scholarships may be given to particular categories of students and that each type of financial aid affects enrollment in a different way. In the example, the classifications of financial aid are the same as the categories of students, but this need not hold in the study of an actual university situation. Scholarships and fellowships, for example, might be separated into undergraduate scholarships, science fellowships, and non-science fellowships. Assistantships might be classified by area of study. For purposes of demonstration, reference is made here to "undergraduate assistantships," e.g., work scholarships.

In any case, Table 4 provides an example of the detailed information. It shows that one assistantship in science graduate work, for example, will attract 1.2 graduate science students and .1 undergraduate science students. It is recognized here that financial aid given in one category may attract students into other categories. For example, awards in Veterinary Medicine may attract undergraduates into a branch of natural science, in anticipation of later financial aid.

If this table is assumed to be a correct description of the effect of financial assistance, then one could examine through the mathematical model what the result would have been if assistance were reduced in some classifications and increased in others, keeping the total amount of financial aid the same. Table 4 indicates that 100 assistantships were awarded in undergraduate science and 50 in graduate science. Each undergraduate assistantship attracted 1 student to undergraduate science, and each graduate assistantship attracted .1 students to undergraduate science, so that the total enrollment attracted to undergraduate science is 105. Each graduate science assistantship attracted 1.2 students to graduate science, for a total of 60.

Now we may examine the effect of awarding the 150 science assistantships so that 75 are for undergraduate science and 75 for graduate science work. This change might be occasioned by a policy decision to increase graduate enrollment or because more assistants are needed to teach. According to the table on the influence of assistantships, only 83 students would be attracted to undergraduate science, and the total enrollment in undergraduate science would be reduced from 1010 to 988. On the other hand, the enrollment attracted to graduate science would increase from 60 to 90, and total enrollment in graduate science would increase, therefore, from 211 to 241. This has had the effect of increasing the percentage of graduate students in the system from 18% to 19.6%. The total enrollment in the university is increased from 1879 to 1887. Table 4-A shows Table 4 revised to conform with the change in aids.

As another example of analysis of the effects of different administrative policy, suppose that assistantships in graduate science were increased by 25 with no reduction elsewhere. Still, undergraduate science enrollment changes as well as graduate science enrollment, so that total university enrollment increases from 1879 to 1912. It is important to note that this change in the graduate science program has an effect on other categories of enrollment, which will be reflected in the demands placed on the Academic Production sector of the university. Table 4-B refers to this pattern of financial aids.

At this time, detailed mathematical analysis of the effect of financial aid on enrollments at Michigan State is not available. However, a research study has been undertaken to obtain the required information. Plans are being made to conduct a sample survey in Fall 1967 to estimate the fraction of the student population that might not have been on the campus but for the financial assistance. A questionnaire is being developed to collect relevant information from a representative sample drawn from each level and category of student population. Appropriate statistical techniques will be used to determine the various important factors and their effect on the student enrollment. This study will be used as a guide in establishing the data which might eventually be included as part of the student master file.

Demands for Academic Service

The students in the system impose a load or demand on the university resources, the greatest being in the area of credit hours of instruction. Students in a given field-level category impose a demand not only on that category but also on other fields and levels of instruction as indicated in Table 5.

Each column of Table 5 (a) indicates the average distribution of course credits for a student in the enrollment category denoted by the column heading. The course credits for any category of student may be distributed over many fields and levels of instruction. In this example, the fields and levels of instruction coincide with the categories of students. In an actual application, however, this need not be true. For particular types of analysis, students may be separated into say six levels of study, while their courses are characterized as lower undergraduate, upper undergraduate and graduate. Similarly, credit hour demands may be studied with students and courses aggregated differently into fields of study.

The credit hour demand described in Table 5 is derived from the period 1 university records of actual student enrollments in courses. The table shows, for example, that an undergraduate student in humanities, on the average, takes 26 credits in undergraduate humanities courses, 20 credits of undergraduate science courses, and 1 credit in graduate science work. If period 1 is regarded as a school year, these values are three-term totals; the average total credit for the year is 47.

Each row of Table 5 (a) is associated with the indicated area of instruction. A given entry shows the number of credit hours of instruction demanded, on the average, by a student in the group indicated by the column heading. The total demand for instruction, measured in student credit hours in each area of instruction, is computed in the right hand column of this table. It also provides an analysis of the teaching load for each field of study to show the source of the demand.

Table 5 (a) provides a similar analysis of the demand for research-teaching, such as dissertation guidance or special studies.

At the present time, Michigan State University student enrollment records are available on computer tape for all terms since Fall 1963. In connection with the system project, computer programs have been developed which will provide all the information contained in Table 5 (a). The user may specify the aggregation of departments and levels of study he wishes to examine.

Academic Production

A description of the demand for academic service imposed on the system by students in all categories has been presented. Of course, there are other demands for academic service--in continuing education, sponsored research, international programs, etc. All these demands are met by the Academic Production sector of the university, using as resources effort of faculty and graduate assistants, classrooms, laboratories, technological equipment, supplies, etc. Table 6, using a limited number of resource classifications, presents an analysis of resources used to meet production demands consistent with the system method.

The list of "units demanded," in Table 6, includes units of sponsored research and "service," as well as the student credit hours and research-teaching indicated in Table 5. At the top of Table 6 are shown the units of resource utilized by the university in academic production. Based on ratios of these demand and resource values, a "policy table" showing the use of resources in production has been developed.

The entries in the body of Table 6 are based on the hypothetical operating data of the university for period 1, the period of activity we have been analyzing. It is assumed that these policy values are re-estimated periodically to provide information on trends in the pattern of resource utilization, independent of the growth in university size. An administrative decision to change utilization of resources can be expressed as change in the appropriate policy values. Simulation of the effect of policy change on resource utilization can then be determined by computer calculation.

A detailed study of this type cannot be made at the present time for Michigan State University, since the required machine-addressable data are not available. However, analysis of available data of this type has shown, for example, that while the faculty and student body have both been increasing, the number of units of effort used in teaching, per student credit hour produced, has been decreasing in most colleges.

Ratios of policy values are important indicators of policy on academic production. Table 6 shows that the unit ratio of faculty effort to graduate assistant effort in Humanities undergraduate instruction is .0015/.0002, or 7.5, while in Science the ratio is .001/.0002, or 5.0, allowing comparison of utilization of graduate assistants. The ratios of human effort to use of technological equipment in undergraduate teaching are .17 and .06 for Humanities and Science respectively. Trends of change over time in these ratios and comparison among different fields of study provide valuable information on administration of the teaching program.

Cost Analysis

Once the resources required in production have been analyzed, unit costs of production may be developed based on known costs of resources used.

In any practical use of the model, the costs of units of faculty teaching effort, or units of classroom space, must be based on analysis of the production of the Personnel and Physical Facilities sectors. These analyses would provide information on units of input needed to produce a unit of faculty teaching effort or a unit of space of any type. It has been pointed out previously that various support resources must be included in computing costs.

In this example, it will be assumed that average unit costs of the items required in academic production have been determined, as exhibited in Table 7 (a). This table also includes total university budgets for these items.

Table 7 (b) gives the average unit costs for each service provided by academic production. These costs are based on the known average unit costs of resources required [Table 7 (a)] and on the analysis of resource utilization given in Table 6. Combining the information in these two tables, we are able to determine, for example, that the average cost of a student credit hour in undergraduate humanities is $15.90 and that the average cost of a student credit hour in graduate humanities is $25.40.

The average costs of units of sponsored research in humanities and science are, respectively, \$104.00 and \$205.00.

Cost of Education

The last item to be given in the analysis of the operation of the university during period 1 is the determination of current average cost of education for students in each category. These costs are given in Table 8. The credit hour and research-teaching demands of students in each category have been analyzed in Table 5. Costs of credit hours and research teaching have been determined in Table 7. The cost of education is computed by combining the information in these previous tables.

The examples presented have centered on analysis of student enrollments and demands and on academic production. Therefore, the values presented as costs of education do not include the costs of non-academic services. In a more detailed analysis, total cost of education would include cost of registration, counseling, evaluation, and other non-academic products.

Prediction and Simulation

The examples presented have also centered on the analysis of some aspects of the operation of the university during period 1, regarded as the current school year for which all operating data is available.

In a prediction of future resource requirements, one may begin with the assumption that all values in the tables which represent either human behavior or administrative policy will remain constant. Based on student transition tables, future enrollment distribution would be predicted. The predicted enrollment, together with average requirements for academic service, based on previous experience, will yield a prediction of required resources. Costs may then be analyzed on the basis of expected salaries and prices for the coming period.

Simulation studies would then allow experimentation with resource and cost changes under changes of behavior or operating policy. Depending on the questions which must be answered, computer programs would allow successive changes in particular policy values.

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(3) Zemach, "A State-Space Model for Resource Allocation in Higher Education," Technical Report, Division of Engineering Research, Michigan State University, 1967.

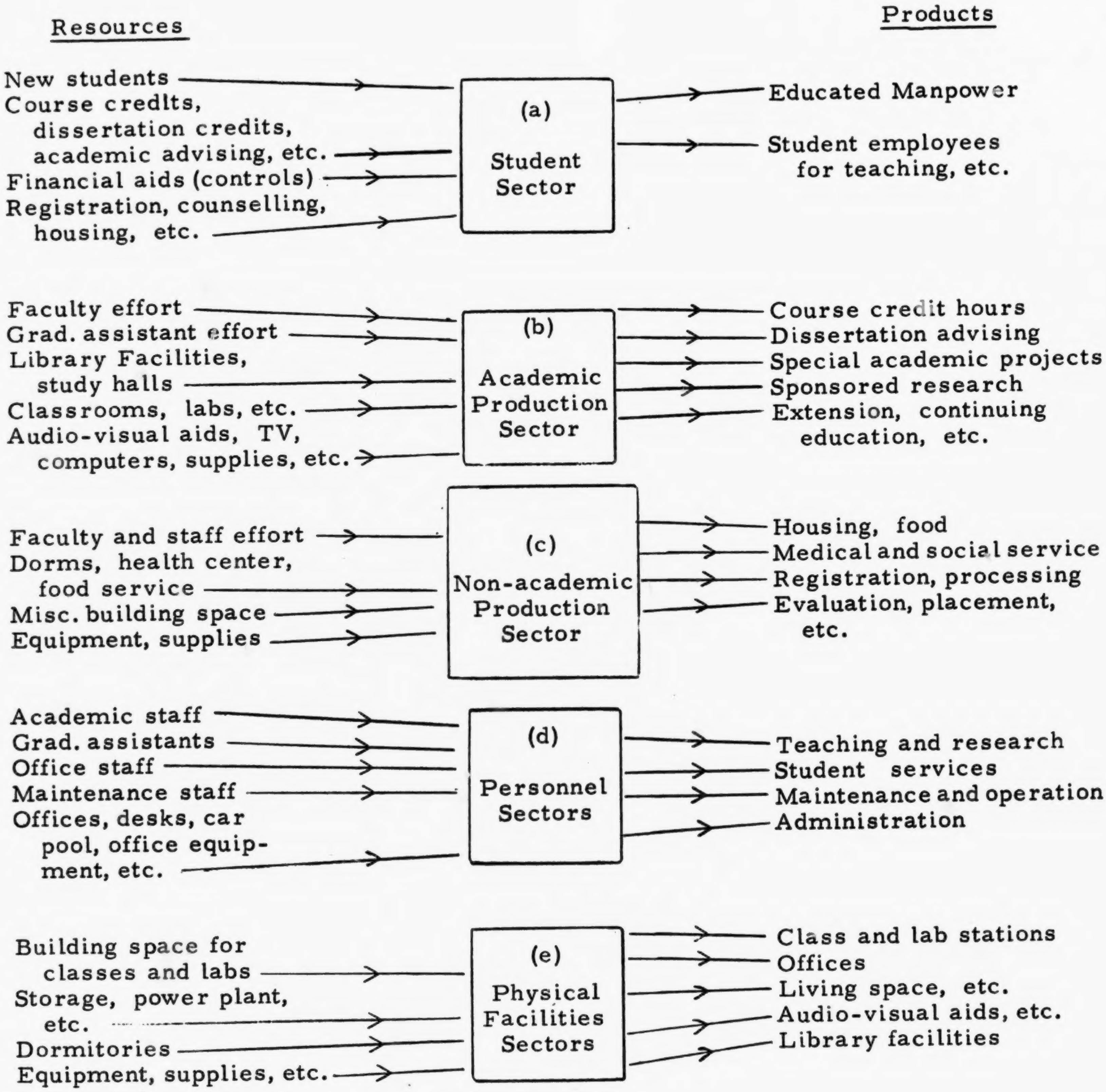
Resources
Products
New students
Course credits, dissertation credits, academic advising, etc.
Financial aids (controls)
Registration, counselling, housing, etc.
(a) Student Sector
Educated Manpower
Student employees for teaching, etc.
Faculty effort
Grad. assistant effort
Library Facilities, study halls
Classrooms, labs, etc.
Audio-visual aids, TV, computers, supplies, etc.
(b) Academic Production Sector
Course credit hours
Dissertation advising
Special academic projects
Sponsored research
Extension, continuing education, etc.
Faculty and staff effort
Dorms, health center, food service
Misc. building space
Equipment, supplies
(c) Non-academic Production Sector
Housing, food
Medical and social service
Registration, processing
Evaluation, placement, etc.
Academic staff
Grad. assistants
Office staff
Maintenance staff
Offices, desks, car pool, office equipment, etc.
(d) Personnel Sectors
Teaching and research
Student services
Maintenance and operation
Administration
Building space for classes and labs
Storage, power plant, etc.
Dormitories
Equipment, supplies, etc.
(e) Physical Facilities Sectors
Class and lab stations
Offices
Living space, etc.
Audio-visual aids, etc.
Library facilities

Figure 1. Sectors of the Model

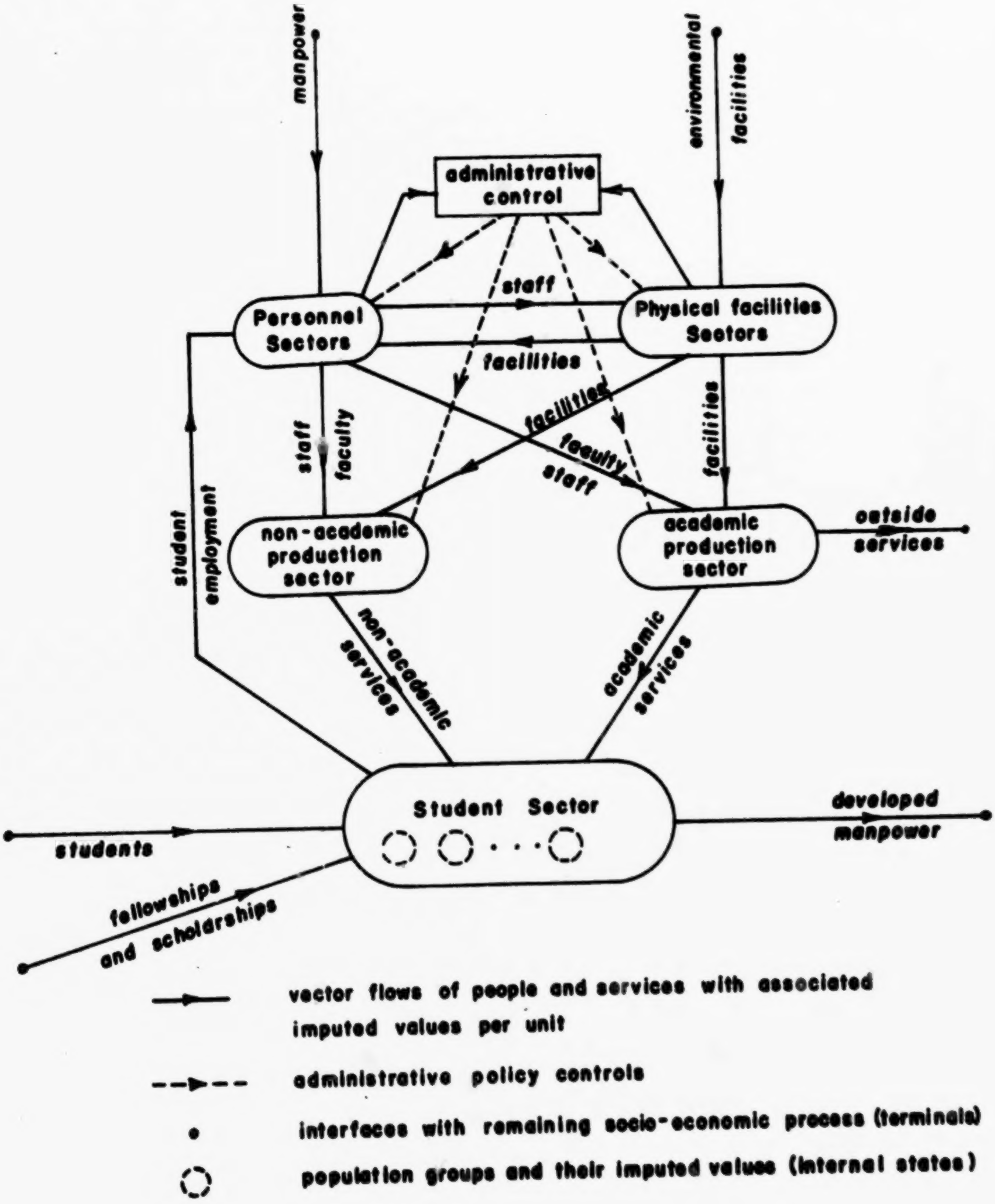
manpower
environmental facilities
administrative control
staff
Personnel Sectors
Physical facilities Sectors
facilities
staff
faculty
facilities
faculty
staff
facilities
non-academic production sector
academic production sector
outside services
student employment
non-academic services
academic services
Student Sector
students
developed manpower
fellowships and scholarships
vector flows of people and services with associated imputed values per unit
administrative policy controls
interfaces with remaining socio-economic process (terminals)
population groups and their imputed values (internal states)

Figure 2. Structure of the System Model

(a) Enrollment: Period 0

Hu	Hg	Su	Sg	Total
500	100	1000	200	1800

↓ ↓ ↓ ↓

(b) Enrollment: Period 1

Hu	530
Hg	128
Su	1010
Sg	211

Total = 1879

←

(c) Transition table

%	No.	%	No.	%	No.	%	No.
57%	285	0	0	11%	110	0	0
6%	30	48%	48	1%	10	10%	20
17%	85	0	0	62%	620	0	0
5%	25	6%	6	6%	60	40%	80
85%	425	54%	54	80%	800	50%	100

←

(d) Distribution of new students

27%	135
4%	20
61%	305
8%	40

500 = total no. of new students

(e) Distribution of students leaving the university

	Hu	Hg	Su	Sg
No. from each category	75	46	200	100
% of previous category enrollment	15%	46%	20%	50%

Total enrollment in Period 1 is determined from transition of previous enrollment and distribution of new students.

[Equation: $s(t) = P(t)\, s(t-1) + a(t)\, n(t)$]

Table 1. Transition of Student Enrollment: Period 0 to Period 1

Enrollment: Period 0

Hu	Hg	Su	Sg
500	100	1000	200

New Students Period 1

500

Enrollment: Period 1

(a) Enrollment independent of financial aid

Transition

New Enrollment

Hu	435	46%	230	0	0	8%	80	0	0	25%	125
Hg	39	2%	10	20%	20	0	0	2%	4	1%	5
Su	865	12%	60	0	0	52%	520	0	0	57%	285
Sg	86	1%	5	1%	1	3%	30	20%	40	2%	10

1425

425 total

(b) Attributed to assistantships

Transition

New Enrollment

Hu	60	9%	45	0	0	1%	10	0	0	1%	5
Hg	50	2%	10	20%	20	0	0	5%	10	2%	10
Su	105	5%	25	0	0	7%	70	0	0	2%	10
Sg	60	2%	10	2%	2	1%	10	9%	18	4%	20

275

45 total

(c) Attributed to fellowships

Transition

New Enrollment

Hu	35	2%	10	0	0	2%	20	0	0	1%	5
Hg	39	2%	10	8%	8	1%	10	3%	6	1%	5
Su	40	0	0	0	0	3%	30	0	0	2%	10
Sg	65	2%	10	3%	3	2%	20	11%	22	2%	10

179

30 total

Enrollment in Period 1 is analyzed to account for the influence of financial aid by separating Table 1 into three parts.

Table 2. Student transition: Adjusted to Account for Financial Aid

Enrollment: Period 0

Hu	Hg	Su	Sg
500	100	1000	200

New Students: Period 1

500

Enrollment Period 1

Hu	435
Hg	39
Su	865
Sg	86
	1425

Enrollment Independent of financial aid

Transition

Hu	46%	230	0	0	8%	80	0	0
Hg	2%	10	20%	20	0	0	2%	4
Su	12%	60	0	0	52%	520	0	0
Sg	1%	5	1%	1	3%	30	20%	40

New Enrollment

Hu	25%	125
Hg	1%	5
Su	57%	285
Sg	2%	10
		425 total

Enrollment attributed to financial aid

	No. assistantships: 250				No. scholarships/fellowships: 143			
	no. transitions		no. new students		no. transitions		no. new students	
	per unit	total	per unit	total	per unit	total	per unit	total
Hu	0.22	55	0.02	5	0.21	30	0.035	5
Hg	0.16	40	0.04	10	0.238	34	0.035	5
Su	0.38	95	0.04	10	0.21	30	0.07	10
Sg	0.16	40	0.08	20	0.384	55	0.07	10
total	0.92	230	0.18	45	1.042	149	0.21	30

Total Enrollment:		
	Hu	530
	Hg	128
	Su	1010
	Sg	211
	total	1879

$$[\, s(t) = P(t)\, s(t-1) + a(t) n(t) + K_1 g(t) + K_2 h(t) \,]$$

Table 3. Student Transition as a Function of Financial Aid

Enrollment: Period 0

Hu	Hg	Su	Sg
500	100	1000	200

New students
Period 1

500

Enrollment:
Period 1

Hu	435
Hg	39
Su	865
Sg	86
	1425

Enrollment independent of financial aid

Transition

46%	230	0	0	8%	80	0	0
2%	10	20%	20	0	0	2%	4
12%	60	0	0	52%	520	0	0
1%	5	1%	1	3%	30	20%	40

New Enrollment

125
5
285
10
425 total

Enrollment per unit of financial aid

	Assistantships: 250				Fellowships and Scholarships: 143			
	aid by categories				aid by categories			
	Hu:50	Hg:50	Su:100	Sg:50	Hu:20	Hg:39	Su:25	Sg:59
Hu	1	0. 2	0	0	1. 2	0. 13	0	0. 1
Hg	0	1	0	0	0	1	0	0
Su	0	0	1	0. 1	0	0	1. 14	0. 2
Sg	0	0	0	1. 2	0	0	0	1. 1
total no. students	50	60	100	65	24	44	28	83

Total Enrollment:		
	Hu	530
	Hg	128
	Su	1010
	Sg	211
	total	1879

Table 4. Student Transition Attributed to Aid by Categories

Enrollment: Period 0

Hu	Hg	Su	Sg
500	100	1000	200

Enrollment independent of financial aid

	Enrollment: Period 1	Transition								New Enrollment
Hu	435	46%	230	0	0	8%	80	0	0	125
Hg	39	2%	10	20%	20	0	0	2%	4	5
Su	865	12%	60	0	0	52%	520	0	0	285
Sg	86	1%	5	1%	1	3%	30	20%	40	10
	1425									425 total

Enrollment per unit of financial aid

	Assistantships: 250				Fellowships and scholarships: 143			
	aid by categories				aid by categories			
	Hu:50	Hg:50	Su:75	Sg:75	Hu:20	Hg:39	Su:25	Sg:59
Hu	1	0.2	0	0	1.2	0.13	0	0.1
Hg	0	1	0	0	0	1	0	0
Su	0	0	1	0.1	0	0	1.14	0.2
Sg	0	0	0	1.2	0	0	0	1.1
total no. students	50	60	75	98	24	44	28	83

Total Enrollment:	
Hu	530
Hg	128
Su	988
Sg	241
Total	1887

Table 4a. Student Transition Attributed to Aid by Categories
Simulated Change in Aid Distribution

Enrollment: Period 0

Hu	Hg	Su	Sg
500	100	1000	200

Enrollment independent of financial aid

	Enrollment: Period 1	Transition								New Enrollment
Hu	435	46%	230	0	0	8%	80	0	0	125
Hg	39	2%	10	20%	20	0	0	2%	4	5
Su	865	12%	60	0	0	52%	520	0	0	285
Sg	86	1%	5	1%	1	3%	30	20%	40	10
	1425									425 total

Enrollment per unit of financial aid

Assistantships: 275

Fellowships and scholarships: 143

	aid by categories				aid by categories			
	Hu:50	Hg:50	Su:100	Sg:75	Hu:20	Hg:39	Su:25	Sg:59
Hu	1	0.2	0	0	1.2	0.13	0	0.1
Hg	0	1	0	0	0	1	0	0
Su	0	0	1	0.1	0	0	1.14	0.2
Sg	0	0	0	1.2	0	0	0	1.1
total no. students	50	60	100	98	24	44	28	83

Total Enrollment:		
	Hu	530
	Hg	128
	Su	1013
	Sg	241
	total	1912

Table 4b. Student Transition Attributed to Aid by Categories
Simulated Increase in Aid

(a) Student Credit Hour Load Distribution

Student Enrollment by Category

Instruction Categories	Hu: 530		Hg: 128		Su: 1010		Sg: 211		Total 1879
	Per Student	Total S. C. H.	Per Student	Total S. C. H.	Per Student	Total S. C. H.	Per Student	Total S. C. H.	Total S. C. H.
Humanities Undergrad.	26	13, 780	--	--	2	2, 020	1	211	16, 011
Humanities Grad.	--	--	23	2, 944	--	--	3	633	3, 577
Science Undergrad.	20	10, 600	3	384	43	43, 430	6	1, 266	55, 680
Science Grad.	1	530	10	1, 280	--	--	26	5, 487	7, 296
Totals	47	24, 910	36	4, 608	45	45, 450	36	7, 596	82, 564

(b) Research-teaching Load Distribution

Instruction Categories	Hu: 530		Hg: 128		Su: 1010		Sg: 211		Total 1879
	Per Student	Total	Per Student	Total	Per Student	Total	Per Student	Total	Total
Humanities Undergrad.	1	530	--	--	--	--	--	--	530
Humanities Grad.	--	--	6	768	--	--	--	--	768
Science Undergrad.	--	--	--	--	1	1, 010	--	--	1, 010
Science Grad.	--	--	--	--	--	--	8	1, 688	1, 688
Totals	1	530	6	768	1	1, 010	8	1, 688	3, 996

$$\begin{bmatrix} c\ (t) \\ r\ (t) \end{bmatrix} = \begin{bmatrix} C \\ R \end{bmatrix} s\ (t)$$

Table 5. Course Credit and Research-Teaching Demands

Units of Resources Utilized

			Fac.: Hum.	Gr. Ass't. Hum.	Fac.: Science	Gr. Ass't. Science	Space		Equipment	
							Class	Lab.	Teach. Equip.	Supplies
	Units of Production Demanded		83	7	160	16	1005	1390	1733	2290
Student Credit Hours	Humanities Undergrad.	16, 011	.0015	.0002	-	-	.01	-	.01	.01
	Humanities Grad.	3. 577	.0025	-	-	-	.02	-	.01	.01
	Science Undergrad.	55, 680	-	-	.001	.0002	.01	.02	.02	.03
	Science Grad.	7, 296	-	-	.002	-	.02	.02	.03	.03
Research Teaching	Human.	1, 298	.026	-	-	-	.01	.01	.02	.02
	Science	2, 698	-	-	.015	-	.01	.01	.04	.04
Sponsored Research	Human.	1.000	.01	.001	-	-	-	.02	.02	.02
	Science	2, 000	-	-	.02	.001	-	.02	.10	.10
	Service	3, 000	.002	.001	.003	.001	.01	.01	.01	.01

Entries denote number of units of resource used per unit of production demanded.

Values are production - resource ratios.

$$\begin{bmatrix} f(t) \\ g(t) \\ e(t) \end{bmatrix} = \begin{bmatrix} F_1 & F_2 & F_3 \\ G_1 & G_2 & G_3 \\ E_1 & E_2 & E_3 \end{bmatrix} \begin{bmatrix} c(t) \\ r(t) \\ o(t) \end{bmatrix}$$

Table 6. Analysis of Resources Required to Meet Academic Demand

(a) Cost of Resources Used in Academic Production

Resource		No. Units Used	Unit Cost	Cost	Totals
Faculty Academic effort	Humanities	83	$10,000	$830,000	2,430,000
	Science	160	10,000	1,600,000	
Grad. Ass't. Academic effort	Humanities	7	3,000	21,000	69,000
	Science	16	3,000	48,000	
Classroom space		1005	10	10,050	30,900
Laboratory Space		1390	15	20,850	
Technological Equipment		1733	10	17,330	28,780
Supplies		2290	15	11,450	

Total Academic Budget $2,558,680

(b) Cost Analysis of Academic Production

		Units Used	Average Unit Cost	Cost	Totals
Humanities	Undergrad. stu. credit hrs.	16,011	$15.90	$254,000	$683,800
	Graduate stu. credit hrs.	3,577	25.40	90,800	
	Research-teaching	1,298	261.00	339,000	
	Sponsored research	1,000	104.00	104,000	104,000
Science	Undergrad. stu. credit hrs.	55,680	11.40	635,000	1,191,680
	Graduate stu. credit hrs.	7,296	21.00	153,000	
	Research-teaching	2,698	151.00	407,000	
	Sponsored research	2,000	205.00	410,000	410,000
	Service	3,000	56.40	169,200	169,200

Total academic budget: $2,558,680

(Average unit costs are based on analysis of required resources, Table 6)

$$\begin{bmatrix}\hat{c}(t)\\ \hat{r}(t)\\ \hat{o}(t)\end{bmatrix} = \begin{bmatrix}F_1 & F_2 & F_3\\ G_1 & G_2 & G_3\\ E_1 & E_2 & E_3\end{bmatrix}^T \begin{bmatrix}\hat{f}(t)\\ \hat{g}(t)\\ \hat{e}(t)\end{bmatrix}$$

Table 7. Analysis of Cost of Academic Production

Academic Cost of Education, Period 1, by Student Enrollment Categories

Categories of Enrollment	Average unit Cost of education
Humanities: undergraduate	$ 924
Humanities: graduate	$2,394
Science: undergraduate	$ 673
Science: graduate	$1,914

Average cost of education based on average student credit hour and research teaching load distribution (Table 5) and average unit cost of academic production (Table 7 (b))

Table 8. Cost of Education

6:2 An Example Simulation

Prepared by

M. J. Keeney
J. H. Fowler
E. D. Goodman

AN EXAMPLE SIMULATION PROGRAM

Prepared for:

Advisory Committee to Project C-518,
"A Systems Approach to Higher Education"
September 14, 1967

Prepared by:

M. G. Keeney
J. H. Fowler
E. D. Goodman

Division of Engineering Research
Michigan State University
East Lansing, Michigan

Examples of the System Analysis and Planning Programs described in this report are now operational on the GE-265 Time-Sharing Computer System. These examples are intended to illustrate to the advisory committee the technique of computer implementation of the model, so that a cooperative effort may be initiated which will result in a design for full-scale programs representing useful tools in decision making. The program can then be constructed and implemented by the administration of any university, if they so choose, at almost any level of detail.

MSUSIM

The simulation program now running on the GE-265 Time-Sharing Computer System operates under the Fortran system. A sample output is shown following the instructions. In a time-sharing computer system a teletypewriter is connected to a computer over regular telephone lines. The user establishes the connection by dialing a telephone number, then communicates with the computer program through the keyboard and printer of the teletypewriter, sharing computer time with any other consoles that are similarly connected. Response times are usually in the order of a few seconds plus the printing time, though with complex programs, or many other users sharing time, this can be a matter of minutes.

INSTRUCTIONS FOR USING MSUSIM

After preparing the program for running, and entering the system command "RUN", the user must wait approximately 1 minute for the program to compile and begin execution.

STEP 1	The user will be asked, "WANT RUN USING ONLY STORED DATA?" The user may elect to see a sample run of the program, demonstrating some of its features and the data values which are assumed, or he may enter "0" and the program will skip to STEP 3. The user must then enter "12" when he reaches STEP 5 in order to cause the initial data to be read.
STEP 2	The program will print the number of new students expected next year, the present year's enrollment and the enrollment projected for next year, then ask what further information the user wants. The user may answer "0" if he wants only the teaching and research budget breakdowns and the total budget.

He answers "1" if he also wants the amount of outside services contracted for by the university and the amount of support facilities needed to support the teaching and research projected for the next year. If the user answers "2", he will obtain the above information plus the faculty and graduate assistant salaries and the cost per unit of support facilities. If the user answers "3," the program skips to STEP 4 (see PRINT KEY following STEP 6).

STEP 3 The user is next instructed that he may see any of a number of tables (see SEE KEY following STEP 6). If he desires to look at one (especially if he wants to change one later),he should enter the appropriate number (as listed by the program before it types the question marks). After the table is printed, the program will again type "? ?" Whenever the user has seen as many of the tables as he desires, he should enter "9" for none (no more).

STEP 4 The user will now be asked if he wishes to change any of the values to be used for the next year (what was up to this point "next year" has become "this year"). If he does not want to make any changes but wants to allow the projection to continue another year, he should type "0". The program then advances to STEP 6. If he decides to stop,he should type "STOP". If he wants to change some value, he should type "1".

STEP 5 The program will now ask if the user wants the key for making changes (see CHANGE KEY, following STEP 6). The first time through the user will, of course, need the key, so he should type "1". On subsequent years, he may wish to enter "0". After the key is printed (or after the answer, if the user entered "0"), the program will type "? ?" and wait for the number indicating what the user wished to change. After the user enters the appropriate number, the program will continue. If "12" was entered, the program fetches the initial data and asks for more changes. If a code for a table (with TBL in the abbreviation) was entered, the program will ask the user to enter a row number (1-4) and 4 entries (separated by commas). Only one row of a table may be changed at a time; however, when the program asks for more changes, additional rows may be changed. When the user enters a code 1-8, the program will ask the user to type in the entries (separated by commas, if there is more than one entry). When the user has made as many changes as he desires for that year, he should enter "13" (no more changes).

STEP 6 The program will now ask if the user wants to see the results for the next year (years numbered from initial data, year 0). If the user enters "1" (yes), the program begins printing the results by returning to STEP 2. If "0" is entered, the program immediately skips to STEP 4.

SEE KEY

No.	Table
1	Assistantship Attraction
2	Scholarship Attraction
3	Class Credits/Student
4	Research Credits/Student
5	Student Transitions
6	New Student Distribution
7	Credit Demand, Current Term
8	Number of Scholarships Given
9	No More Tables to be Printed

PRINT KEY

0	Teaching, Research and Total Budgets
1	Above, Plus Facilities and Staff Required
2	Above, Plus Salary and Support Rates
3	No Printout, for Fast Progression to Subsequent Terms

CHANGE KEY

1	Number of New Students
2	Number of Outside Services Sold
3	Cost/Support Facility
4	Enrollment This Year
5	New Student Distribution
6	Cost/Faculty Member
7	Cost/Assistantship
8	Transition Table
9	Number of Scholarships
10	Class Credits/Student
11	Research Credits/Student
12	Initial Data
13	No More Changes

Note: All entries to the computer should be made carefully and checked before the "return" key is pressed. If a mistake is discovered, the "ESC" key should be pushed and the entire line of date re-entered before "return" is pushed.

BASE PERIOD, YEAR 0. SUCCEEDING PAGES DIFFER ONLY AS INDICATED

```
    IN PART2

EDUCATIONAL SIMULATION PROGRAM

WANT RUN USING ONLY STORED DATA?  INPUT 0 FOR NO, 1 FOR YES
? ?1
NO. OF NEW STU    1500
                           ENGINEERING          NON-ENGINEERING
                         UNDERGRAD    GRAD   UNDERGRAD     GRAD
ENROLLMENT THIS YEAR       305.        72.     3000.        484.
ENROLLMENT NEXT YEAR       305.        72.     3000.        484.
WANT MORE INFO? (0=COST TOTALS ONLY,1=ALL BUT RATES,2=ALL,3=NO MORE)? ?2
                           ENGINEERING          NON-ENGINEERING
                          TEACH    RESEARCH   TEACH    RESEARCH
$/FTE GRAD ASSTSHIP       4400.     4800.     4400.     4800.
FTE ASSTSHIPS NEEDED        6.       15.        66.       20.
                           ENGINEERING          NON-ENGINEERING
                         UNDERGRAD    GRAD   UNDERGRAD     GRAD
$/FTE FACULTY MEMBER
     TO TEACH              13000.    14000.    12000.     13000.
FTE FACULTY NEEDED
     TO TEACH                17.       10.       136.        66.

$/SUPPORT FACILITY       3000.00

AMOUNT OF SUPPORT FACILITIES NEEDED      793.1661

NO. OF OUTSIDE SERVICES SOLD       25.00

FAC AND GRAD ASST
   TEACHING BUDGET         244071.   144215.  1925677.   864156.
   RESEARCH BUDGET:  ENGIN     74175.00   NON-ENGIN     96000.00

TOTAL BUDGET--FACULTY,GRAD ASST.,AND SUPPORT  5729778.70
```

PARAMETER TABLES OF THE PROGRAM

```
YOU MAY SEE: ASS'TSHIP ATTRACTION TBL-1;SCHLRSHP ATTR TBL-2;
CLASS CRED TBL-3;RESEARCH CRED TBL-4;STU TRANSITION TBL-5;
PERCENT BRKDWN OF NEW STU-6;CURRENT CREDIT DEMAND-7;SCHOLARSHIPS-8;
NONE (NO MORE)-9? ?1
     .0500      .0400    0.0000    0.0000
     .6600      .7600     .0500     .0400
    0.0000     0.0000     .0600     .0600
     .1200      .0900     .7500     .8000
? ?2
     .7000     0.0000     .0750    0.0000
     .2000      .8000    0.0000    0.0000
    0.0000     0.0000     .6000    0.0000
    0.0000     0.0000    0.0000     .9000
? ?3
   33.0000     6.0000     .5000     .1000
    2.0000    21.0000     .0500     .1000
   10.0000     0.0000   42.0000    6.0000
    0.0000     9.0000    1.5000   20.0000
? ?4
    0.0000     0.0000    0.0000    0.0000
    0.0000     5.0000    0.0000     .1000
    0.0000     0.0000    0.0000    0.0000
    0.0000     0.0000     .3000    6.0000
? ?5
STUDENT TRANSITION TABLE
ENGIN UNGR          .45000   0.00000    .00100   0.00000
ENGIN GRAD          .02000    .30000    .00100    .02000
N-ENG UNGR          .10000   0.00000    .60000   0.00000
N-ENG GRAD          .01000    .09000    .05000    .40000
? ?6
     9.70       .50     75.50      6.50
? ?8
NO. OF SCHOLARSHIPS,ETC.
       20.       10.       60.       18.
? ?9
```

10% INCREASE IN THE NEW STUDENTS ESTIMATE

```
ANY CHANGES FOR YEAR       2?  (0=NO,1=YES)? ?1
WANT KEY FOR CHANGES?  (0=NO,1=YES)? ?1
(NO OF NEW STU-1;OUTSD SERV-2;$?SPPRT FACIL-3;ENROLMNT-4
PERCENT BRKDWN OF NEW STU-5;$/FAC MEM-6;$/GRAD ASST.-7;
SCHLRSHPS-8;TRANS TBL-9;CLASS CRED TBL-10;RESEARCH CRED TBL-11;
BACK TO YEAR 0 (INITIAL DATA)-12;NO MORE CHANGES-13)
? ?12
MORE CHANGES? ?1
PLEASE TYPE IN THE ENTRIES AFTER '?'
? ?1650
MORE CHANGES? ?13
WANT TO SEE RESULTS FOR YEAR  1?  (0=NO,1=YES)
? ?1
NO. OF NEW STU    1650
                          ENGINEERING        NON-ENGINEERING
                       UNDERGRAD    GRAD   UNDERGRAD    GRAD
ENROLLMENT THIS YEAR      305.       72.     3000.       484.
ENROLLMENT NEXT YEAR      319.       73.     3113.       494.
WANT MORE INFO? (0=COST TOTALS ONLY,1=ALL BUT RATES,2=ALL,3=NO MORE)? ?2
                          ENGINEERING        NON-ENGINEERING
                         TEACH    RESEARCH   TEACH    RESEARCH
$/FTE GRAD ASSTSHIP      4400.     4800.     4400.     4800.
FTE ASSTSHIPS NEEDED        6.       15.       68.       20.
                          ENGINEERING        NON-ENGINEERING
                       UNDERGRAD    GRAD   UNDERGRAD    GRAD
$/FTE FACULTY MEMBER
     TO TEACH            13000.    14000.    12000.    13000.
FTE FACULTY NEEDED
     TO TEACH               17.       10.      141.       68.

$/SUPPORT FACILITY      3000.00

AMOUNT OF SUPPORT FACILITIES NEEDED      820.979

NO. OF OUTSIDE SERVICES SOLD       25.00

FAC AND GRAD ASST
   TEACHING BUDGET         251608.   145583.  1991354.   882930.
   RESEARCH BUDGET:  ENGIN    74175.00   NON-ENGIN    96000.00

TOTAL BUDGET--FACULTY,GRAD ASST.,AND SUPPORT  5906573.70
```

10% INCREASE IN THE UNIT COST OF SUPPORT FACILITIES

```
ANY CHANGES FOR YEAR        2?  (0=NO,1=YES)? ?1
WANT KEY FOR CHANGES?  (0=NO,1=YES)? ?0
? ?12
MORE CHANGES? ?3
PLEASE TYPE IN THE ENTRIES AFTER '?'
? ?3300
MORE CHANGES? ?13
WANT TO SEE RESULTS FOR YEAR  1?  (0=NO,1=YES)
? ?1
NO. OF NEW STU    1500
                            ENGINEERING        NON-ENGINEERING
                          UNDERGRAD    GRAD   UNDERGRAD    GRAD
ENROLLMENT THIS YEAR        305.        72.     3000.       484.
ENROLLMENT NEXT YEAR        305.        72.     3000.       484.
WANT MORE INFO? (0=COST TOTALS ONLY,1=ALL BUT RATES,2=ALL,3=NO MORE)? ?2
                            ENGINEERING        NON-ENGINEERING
                           TEACH    RESEARCH   TEACH    RESEARCH
$/FTE GRAD ASSTSHIP        4400.     4800.     4400.     4800.
FTE ASSTSHIPS NEEDED         6.        15.       66.       20.
                            ENGINEERING        NON-ENGINEERING
                          UNDERGRAD    GRAD   UNDERGRAD    GRAD
$/FTE FACULTY MEMBER
     TO TEACH               13000.    14000.    12000.    13000.
FTE FACULTY NEEDED
     TO TEACH                 17.       10.       136.       66.

$/SUPPORT FACILITY        3300.00

AMOUNT OF SUPPORT FACILITIES NEEDED     793.1661

NO. OF OUTSIDE SERVICES SOLD      25.00

FAC AND GRAD ASST
   TEACHING BUDGET          244071.   144215.  1925677.   864156.
   RESEARCH BUDGET:  ENGIN    74175.00   NON-ENGIN    96000.00

TOTAL BUDGET--FACULTY,GRAD ASST.,AND SUPPORT  5967728.50
```

CHANGE IN DISTRIBUTION OF NEW UNDERGRADUATE STUDENTS

```
ANY CHANGES FOR YEAR       2?  (0=NO,1=YES)? ?1
WANT KEY FOR CHANGES?  (0=NO,1=YES)? ?0
? ?12
MORE CHANGES? ?5
PLEASE TYPE IN THE ENTRIES AFTER '?'
? ?12,.50,72,6.5
MORE CHANGES? ?13
WANT TO SEE RESULTS FOR YEAR  1?  (0=NO,1=YES)
? ?1
NO. OF NEW STU    1500
                           ENGINEERING        NON-ENGINEERING
                         UNDERGRAD    GRAD   UNDERGRAD    GRAD
ENROLLMENT THIS YEAR        305.       72.     3000.       484.
ENROLLMENT NEXT YEAR        339.       72.     2948.       484.
WANT MORE INFO? (0=COST TOTALS ONLY,1=ALL BUT RATES,2=ALL,3=NO MORE)? ?2
                           ENGINEERING        NON-ENGINEERING
                          TEACH    RESEARCH   TEACH    RESEARCH
$/FTE GRAD ASSTSHIP       4400.     4800.     4400.     4800.
FTE ASSTSHIPS NEEDED         7.       15.       65.       20.
                           ENGINEERING        NON-ENGINEERING
                         UNDERGRAD    GRAD   UNDERGRAD    GRAD

$/FTE FACULTY MEMBER
    TO TEACH              13000.    14000.    12000.    13000.
FTE FACULTY NEEDED
    TO TEACH                 18.       10.      135.       66.

$/SUPPORT FACILITY       3000.00

AMOUNT OF SUPPORT FACILITIES NEEDED     788.3393

NO. OF OUTSIDE SERVICES SOLD      25.00

FAC AND GRAD ASST
  TEACHING BUDGET         259531.   145125.  1901050.   860778.
  RESEARCH BUDGET:  ENGIN    74175.00   NON-ENGIN    96000.00

TOTAL BUDGET--FACULTY,GRAD ASST.,AND SUPPORT  5703664.40
```

10% INCREASE IN UNIT COST OF FACULTY MEMBERS

```
ANY CHANGES FOR YEAR       2?  (0=NO,1=YES)? ?1
WANT KEY FOR CHANGES?  (0=NO,1=YES)? ?0
? ?12
MORE CHANGES? ?6
PLEASE TYPE IN THE ENTRIES AFTER '?'
? ?14300,15400,13200,14300
MORE CHANGES? ?13
WANT TO SEE RESULTS FOR YEAR   1?  (0=NO,1=YES)
? ?1
NO. OF NEW STU    1500
                           ENGINEERING       NON-ENGINEERING
                        UNDERGRAD    GRAD   UNDERGRAD    GRAD
ENROLLMENT THIS YEAR      305.       72.    3000.       484.
ENROLLMENT NEXT YEAR      305.       72.    3000.       484.
WANT MORE INFO? (0=COST TOTALS ONLY,1=ALL BUT RATES,2=ALL,3=NO MORE)? ?2
                           ENGINEERING       NON-ENGINEERING
                         TEACH    RESEARCH   TEACH    RESEARCH
$/FTE GRAD ASSTSHIP      4400.     4800.     4400.     4800.
FTE ASSTSHIPS NEEDED        6.        15.      66.       20.
                           ENGINEERING       NON-ENGINEERING
                        UNDERGRAD    GRAD   UNDERGRAD    GRAD
$/FTE FACULTY MEMBER
     TO TEACH                 14300.    15400.    13200.    14300.
FTE FACULTY NEEDED
     TO TEACH                    17.       10.      136.       66.

$/SUPPORT FACILITY      3000.00

AMOUNT OF SUPPORT FACILITIES NEEDED     793.1661

NO. OF OUTSIDE SERVICES SOLD      25.00

FAC AND GRAD ASST
   TEACHING BUDGET        265829.   158636.  2089213.  950572.
   RESEARCH BUDGET:  ENGIN    74392.50   NON-ENGIN    96000.00

TOTAL BUDGET--FACULTY,GRAD ASST.,AND SUPPORT  6016326.00
```

10% INCREASE IN UNIT COST OF GRADUATE ASSISTANTSHIPS

```
ANY CHANGES FOR YEAR       2?  (0=NO,1=YES)? ?1
WANT KEY FOR CHANGES?  (0=NO,1=YES)? ?0
? ?12
MORE CHANGES? ?7
PLEASE TYPE IN THE ENTRIES AFTER '?'
? ?4840,5280,4840,5280
MORE CHANGES? ?13
WANT TO SEE RESULTS FOR YEAR  1?  (0=NO,1=YES)
? ?1
NO. OF NEW STU    1500
                            ENGINEERING       NON-ENGINEERING
                         UNDERGRAD    GRAD   UNDERGRAD    GRAD
ENROLLMENT THIS YEAR        305.       72.     3000.       484.
ENROLLMENT NEXT YEAR        305.       72.     3000.       484.
WANT MORE INFO? (0=COST TOTALS ONLY,1=ALL BUT RATES,2=ALL,3=NO MORE)? ?2
                            ENGINEERING       NON-ENGINEERING
                           TEACH   RESEARCH  TEACH    RESEARCH
$/FTE GRAD ASSTSHIP        4840.    5280.    4840.     5280.
FTE ASSTSHIPS NEEDED         6>      15.      66.       20.
                            ENGINEERING       NON-ENGINEERING
                         UNDERGRAD    GRAD   UNDERGRAD    GRAD
$/FTE FACULTY MEMBER
     TO TEACH              13000.    14000.    12000.    13000.
FTE FACULTY NEEDED
     TO TEACH                 17.       10.      136.        66.

$/SUPPORT FACILITY       3000.00

AMOUNT OF SUPPORT FACILITIES NEEDED      793.1661

NO. OF OUTSIDE SERVICES SOLD       25.00

FAC AND GRAD ASST
   TEACHING BUDGET         246720.   144215.  1954708.   864156.
   RESEARCH BUDGET:  ENGIN    81375.00   NON-ENGIN   105600.00

TOTAL BUDGET--FACULTY,GRAD ASST.,AND SUPPORT  5778259.30
```

20% INCREASE IN THE NUMBER OF ENGINEERING GRADUATE SCHOLARSHIPS

```
ANY CHANGES FOR YEAR        2?  (0=NO,1=YES)? ?1
WANT KEY FOR CHANGES?  (0=NO,1=YES)? ?0
? ?12
MORE CHANGES? ?8
PLEASE TYPE IN THE ENTRIES AFTER '?'
? ?20,12,60,18
MORE CHANGES? ?13
WANT TO SEE RESULTS FOR YEAR  1?  (0=NO,1=YES)
? ?1
NO. OF NEW STU    1500
                           ENGINEERING       NON-ENGINEERING
                        UNDERGRAD    GRAD   UNDERGRAD    GRAD
ENROLLMENT THIS YEAR      305.        72.     3000.       484.
ENROLLMENT NEXT YEAR      305.        74.     3000.       484.
WANT MORE INFO? (0=COST TOTALS ONLY,1=ALL BUT RATES,2=ALL,3=NO MORE)? ?2
                           ENGINEERING       NON-ENGINEERING
                         TEACH    RESEARCH   TEACH    RESEARCH
$/FTE GRAD ASSTSHIP      4400.     4800.     4400.     4800.
FTE ASSTSHIPS NEEDED        6.       15.       66.       20.
                           ENGINEERING       NON-ENGINEERING
                        UNDERGRAD    GRAD   UNDERGRAD    GRAD
$/FTE FACULTY MEMBER
     TO TEACH             13000.    14000.    12000.    13000.
FTE FACULTY NEEDED
     TO TEACH               17.       10.       136.        66.

$/SUPPORT FACILITY      3000.00

AMOUNT OF SUPPORT FACILITIES NEEDED     793.3381

NO. OF OUTSIDE SERVICES SOLD      25.00

FAC AND GRAD ASST
   TEACHING BUDGET          244204.   145796.  1925677.   864324.
   RESEARCH BUDGET:  ENGIN    74175.00   NON-ENGIN    96000.00

TOTAL BUDGET--FACULTY,GRAD ASST.,AND SUPPORT  5732177.60
```

25% INCREASE IN ENGINEERING TRANSITIONS FROM UNDERGRADUATE TO GRADUATE

```
ANY CHANGES FOR YEAR       2?  (0=NO,1=YES)? ?1
WANT KEY FOR CHANGES?  (0=NO,1=YES)? ?0
? ?12
MORE CHANGES? ?9
PLEASE TYPE IN THE ENTRIES AFTER '?'
TYPE IN A ROW NUMBER AND 4 ENTRIES
? ?2,.025,.3,.001,.02
MORE CHANGES? ?13
WANT TO SEE RESULTS FOR YEAR  1?  (0=NO,1=YES)
? ?1
NO. OF NEW STU    1500
                           ENGINEERING       NON-ENGINEERING
                        UNDERGRAD    GRAD   UNDERGRAD    GRAD
ENROLLMENT THIS YEAR      305.        72.      3000.      484.
ENROLLMENT NEXT YEAR      305.        74.      3000.      484.
WANT MORE INFO? (0=COST TOTALS ONLY,1=ALL BUT RATES,2=ALL,3=NO MORE)? ?2
                           ENGINEERING       NON-ENGINEERING
                         TEACH    RESEARCH   TEACH    RESEARCH
$/FTE GRAD ASSTSHIP      4400.     4800.     4400.     4800.
FTE ASSTSHIPS NEEDED        6.        15.       66.       20.
                           ENGINEERING       NON-ENGINEERING
                        UNDERGRAD    GRAD   UNDERGRAD    GRAD
$/FTE FACULTY MEMBER
     TO TEACH             13000.    14000.    12000.    13000.
FTE FACULTY NEEDED
     TO TEACH                17.       10.      136.       66.

$/SUPPORT FACILITY      3000.00

AMOUNT OF SUPPORT FACILITIES NEEDED     793.33

NO. OF OUTSIDE SERVICES SOLD     25.00

FAC AND GRAD ASST
   TEACHING BUDGET        244198.   145722.  1925677.   864317.
   RESEARCH BUDGET:  ENGIN    74175.00   NON-ENGIN    96000.00

TOTAL BUDGET--FACULTY,GRAD ASST.,AND SUPPORT 5732065.10
```

ENGINEERING GRADUATES TAKE 3 MORE HOURS IN ENGINEERING, 3 LESS IN NON-ENGINEERING SUBJECTS

```
ANY CHANGES FOR YEAR       2?  (0=NO,1=YES)? ?1
WANT KEY FOR CHANGES?  (0=NO,1=YES)? ?0
? ?12
MORE CHANGES? ?10
PLEASE TYPE IN THE ENTRIES AFTER '?'
TYPE IN A ROW NUMBER AND 4 ENTRIES
? ?2,24,.05,1←.1 DELETED
2,2,24,.05,.1
MORE CHANGES? ?10
PLEASE TYPE IN THE ENTRIES AFTER '?'
TYPE IN A ROW NUMBER AND 4 ENTRIES
? ?4,0,6,1.5,20
MORE CHANGES? ?13
WANT TO SEE RESULTS FOR YEAR  1?  (0=NO,1=YES)
? ?1
NO. OF NEW STU    1500
                           ENGINEERING       NON-ENGINEERING
                        UNDERGRAD    GRAD   UNDERGRAD    GRAD
ENROLLMENT THIS YEAR      305.        72.     3000.       484.
ENROLLMENT NEXT YEAR      305.        72.     3000.       484.
WANT MORE INFO? (0=COST TOTALS ONLY,1=ALL BUT RATES,2=ALL,3=NO MORE)? ?2
                           ENGINEERING       NON-ENGINEERING
                         TEACH    RESEARCH   TEACH    RESEARCH
$/FTE GRAD ASSTSHIP      4400.     4800.     4400.     4800.
FTE ASSTSHIPS NEEDED        6.       15.       66.       20.
                           ENGINEERING       NON-ENGINEERING
                         UNDERGRAD    GRAD   UNDERGRAD    GRAD
$/FTE FACULTY MEMBER
     TO TEACH              13000.    14000.    12000.    13000.
FTE FACULTY NEEDED
     TO TEACH                 17.       11.      136.       66.

$/SUPPORT FACILITY      3000.00

AMOUNT OF SUPPORT FACILITIES NEEDED     793.3823

NO. OF OUTSIDE SERVICES SOLD      25.00

FAC AND GRAD ASST
   TEACHING BUDGET         244071.   147182.  1925677.   861626.
   RESEARCH BUDGET:  ENGIN    74175.00   NON-ENGIN    96000.00

TOTAL BUDGET--FACULTY,GRAD ASST.,AND SUPPORT  5730864.20
```

6:3 A Prototype Planning and Resource Allocation Program for Higher Education

Prepared by

H. E. Koenig
M. G. Keeney

A Prototype Planning and Resource Allocation Program for Higher Education*

by

Herman E. Koenig
and
Martin G. Keeney

A Report on Research

by

Herman E. Koenig
Martin G. Keeney and
Rita Zemach

Systems Science Program
College of Engineering
Michigan State University

Presented at the
Symposium on Operations Analysis of Education
National Center for Educational Statistics
U.S. Office of Education
November 19-22, 1967

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INTRODUCTION

Computer implemented procedures for dealing with the problems of planning and resource allocation in educational institutions are invariably motivated by the desire to analyze and "optimize," in some sense, the operation of one or more sectors of the institution. In general terms, the questions of concern include: "What set of allocations of limited resources will result in minimum cost of education given an acceptable level of quality?" or "What sequence of operating policies and allocations will produce the desired type of educated manpower at minimum cost over a period of x years?"

As this paper indicates, it is possible to derive a set of mathematical relationships among the time-functions representing the inputs, the outputs, and the internal states that can serve as the basis for formal application of optimal control and planning theory. These mathematical relations are known technically as a state-space model. It is unlikely that mathematically described control policies can or should be applied in the near future to a social system as complex as a modern university. A more practical approach, at present, is to provide the planner or decision maker with a variety of computer programs which will allow him to explore the consequences of alternate policies in the allocation of resources.

The number of such programs that might be constructed from a given set of mathematical relations on the inputs, outputs, and internal states is large and the particular features they might include are quite varied. In addition, the cost of constructing the programs and providing a data base for their use is high for the number of levels of disaggregation generally required for effective application. These considerations suggest that the programs should be well designed before they are actually implemented. The prototype programs presented in this paper was developed specifically for that purpose. The theoretical foundations and detailed development of the model upon which this prototype is based are given elsewhere [1, 2, 3] with only a brief description of the model and its conceptual structure included here.

DESCRIPTION OF THE MODEL

The model, upon which the prototype program presented in this paper is based, is a mathematical description of the way the university utilizes its resources in production. The resources of the university are described, broadly, as personnel, space, and equipment. The products are identified as developed manpower, research, and public or technical services. No attempt is made to define the academic goals of higher education nor to determine optimal allocation policies nor to design decision-making procedures as such. Instead, the purpose is to provide a rational basis for evaluating alternate allocation policies under the assumption that the university has varied and perhaps conflicting goals defined by those entrusted with decision-making responsibilities.

In comparing these alternate allocation policies, consideration must be given both to the feasibility of achieving a given set of the desired goals, and to the cost of implementation. Will additional personnel be required? Will space be diverted from some other use? And finally, what will be the total budgetary requirements?

No matter how limited the goal, each policy decision affects the operation of the entire university, and the related cost can only be determined by taking into account the total pattern of resource requirements. The effect of changes in the social and economic environment must also be accounted for. In addition, since the university is a dynamic institution, changing through time, the time-horizon for achieving objectives must be a factor in policy decisions. For all these reasons, mathematical models designed to aid in resource allocation and other administrative decisions must be based on a description of the university as a total dynamic, interrelated system.

The model itself consists of sets of equations which describe the relationship of resources to production, and, based on these, the associated cost of production.

For discrete time points, the equations have the general form:

$$\underline{\psi}(t+1) = F[\overset{\text{system states}}{\underline{\psi}(t)}, \overset{\text{policy parameters}}{\underline{\alpha}(t)}, \overset{\text{exogenous variables}}{\underline{\beta}(t)}, \overset{\text{control variables}}{\underline{\gamma}(t)}] \tag{1}$$

$$\underset{\text{response variables}}{\underline{\theta}(t)} = G[\underline{\psi}(t), \underline{\alpha}(t), \underline{\beta}(t), \underline{\gamma}(t)]$$

where $\underline{\psi}(t)$, $\underline{\alpha}(t)$, $\underline{\beta}(t)$, $\underline{\gamma}(t)$ and $\underline{\theta}(t)$ are finite vectors.

The vector $\underline{\psi}(t)$ is said to represent the internal state of the system. Its components are identified as the numbers of students in various fields and levels of education and the associated unit values of education received.

The state of the university at time $(t + 1)$ is determined as a function of its state at a prior time t, the prevailing policy parameters, and inputs of resources into the system. The components $\underline{\beta}(t)$ are inputs considered to be outside the domain of control--such as prevailing prices or flows of new students--whereas the control variables $\underline{\gamma}(t)$ are, to some extent, within the control of administrators. Changes in the policy parameters and control variables affect the future state or position of the system. The response variables, such as output of educated manpower, research, and services, are a function of these same variables.

These equations are similar in form to those used by engineers to describe mathematically the behavior of a physical system as it operates over successive periods of time; consequently it is possible to explore the application of system theory to the university system.

Formal application of control theory to management and planning for a university is particularly challenging. The control problem in its most general context is: for some well-defined goal, determine the sequence of operating policies and controls required to achieve this goal in an optimum manner. The goals must be determined taking into account both the social demands of the population and the economic and cultural needs and resources of the local, national, or world community.

The system model or mathematical description is used here as the "logic" of computer programs which operate in such a way that the consequences of alternate policies in the allocation of resources and the implementation of designated controls can be evaluated. The model has provisions for including descriptive equations for control factors, and the nature of some of them are identified explicitly. It is certainly well-recognized, for example, that the availability of scholarships, fellowships, and assistantships influences the composition of the student body. These financial aids, therefore, constitute a control factor in the formal sense and are included in the mathematical description. A detailed study of the specific nature of the influence of financial aids is being pursued. In order to be included, quality of education must be defined in measurable terms. In addition, a variety of exogenous factors affect the system, many of them unmeasurable and, indeed, often unperceived.

As these other factors are identified and quantified, their influence can readily be incorporated in the mathematical description.

STRUCTURE OF THE MODEL

In accordance with standard engineering practices, the total model, or description, is composed of several sectors or components. Each sector is related to a specific aspect of operation of the university. Equations are associated with each sector to describe the relationship among the services produced, the resources required, and the demands imposed on other sectors of the university. The sector descriptions are simple in form and may be studied independently. The total model is formed by describing the constraints, or restrictions, which the different sectors impose on one another.

The following paragraphs provide a brief description of the sector models, including the information contained in and produced by the mathematical descriptions. The sectors or "building blocks" of the model are summarized schematically in Figure 1.

The Student Sector [Figure 1 (a)]

The internal state, or condition, of the university at any particular time is described in terms of the distribution of students among the various areas of education and levels of study and the respective average accumulated costs per student of education to that point in time. The equations of the student sector describe the dependence of the enrollment distribution on the previous year's distribution, its dependence on the enrollment choices of new students, and its dependence on available graduate assistantships, fellowships, scholarships, and other financial aids. The form of the equations also allows the inclusion of other factors which influence student enrollment, if they can be described quantitatively.

The model of the student sector also describes the number and educational status of the students who leave the university--their fields of study, matriculation levels and the average "cost", or investment, per student accumulated to the time of departure. Finally, the model of the student sector determines from the enrollment distribution the number of student credit-hours of classroom, laboratory and research-teaching that must be produced to satisfy the demands of the student body.

The parameters (coefficients in the equations) of the student sector depend on the behavioral patterns of the students in shifting from one category to another, in selecting courses, and in response to financial aid. Computer programs have been written to produce much of this information from existing machine addressable files on the students at Michigan State University. These files do not, however, include sufficient information to identify explicitly the influence of financial aid on enrollments. Consequently, validation and stability tests are very limited at present.

In all these descriptions, it is possible to separate out special groups of students, according to any item contained in student record files. For example, programs may be written to produce information on married students only, on Michigan residents, or on students as distinguished by grade-point average. Present programs allow the user to choose any groupings of departments and levels of study which would be meaningful for the questions he needs answered.

Academic Production [Figure 1 (b)]

The student sector model generates a particular pattern of demand for course-credit-hours and research-teaching associated with dissertation research. These may be referred to as academic services. Other academic services, such as sponsored research, continuing education, or special programs, are similarly demanded by the community outside the university. The equations of a sector of the model called Academic Production describe the relationship between the quantities of academic services produced and the quantities of faculty effort, graduate assistant effort, and environmental facilities, such as classrooms, laboratories, and technological equipment, required to produce these academic services.

The description of this sector includes the cost of services produced, based on the costs of resources required. These costs determine the cost of education, referred to in the student sector, as well as the cost of sponsored research and other services.

The parameters (coefficients in the equation) of the Academic Production sector represent the policies followed by the administration in allocating resources to meet the academic demands. They include, in particular, such ratios as full-time-equivalent faculty per student-credit-hour by rank and field and level. These policies theoretically are within the control of the administration and are presumably selected so that the resulting "mix" of resources results in academic services of a high quality. Consequently, it is not necessary to determine them from past records, except as required to establish the validity of the structural form of the model and to monitor the system to determine what the current operating policies actually are---in contrast to what they were intended to be. As a practical expedient, almost any administrator would want to take prevailing allocation policies as a starting point in any decision making study.

A machine-addressable file from which prevailing academic production policies can be evaluated is not currently available at Michigan State University, but the basic design of such a file has been established [1].

Non-academic Production [Figure 1 (c)]

Services such as housing, registration, counseling, or medical service must also be produced to satisfy student demands. The equations of the sector known as Non-academic Production again indicate the quantities of effort and facilities required to meet these demands, as well as the imputed unit cost of production.

As in the case of the academic production parameters, the policy parameters in the non-academic production sector are within certain limits, under the control of the administration. Again, machine-addressable files from which prevailing policy parameters can be evaluated are very desirable if not necessary.

Personnel and Physical Facilities [1 (d) and (e)]

The resources required by the Academic and Non-academic Production sectors--various types of personnel effort and various types of space or environmental facilities--are in turn produced by sectors of university operation referred to in the model as Personnel and Physical Facilities. To produce faculty teaching effort, for example, the university must utilize not only the "labor" of the academic employees themselves but also the labor of secretaries and other supporting staff and the office space and other facilities required to maintain the academic staff on the campus. Equations of the Personnel sector indicate the quantity of each of these resources used to produce a given number of units of effort, of all types, required by the Production sectors.

Information giving the costs of resources required by the production sectors is also included. These costs are based on total requirements. This means, for example, that the cost of a unit of faculty service is computed on the basis of average faculty salary, average cost of office space and equipment, cost of

6

a percentage of supporting secretarial effort, and other secondary costs related to academic personnel. Similarly, the average of classroom units includes maintenance and operation. If capital investment costs can be allocated on the basis of use of facilities, these costs may be incorporated into the cost-of-production information.

The prevailing policy parameters in the Personnel and Physical Facilities sector are implicit in the accounting records of the university, but to determine them explicitly from manually addressed files is not really practical except for highly aggregated studies. Consequently, extensive use of this sector model in analysis and resource allocation must await further developments in computer-based accounting systems.

Administrative Control

Units of effort and facilities are also required by the sector identified as Administrative Control. However, the administrative policy decisions produced as "output" by this sector are not described in quantitative units. Rather, the policy decisions produced by the Administrative Control sector are viewed as allocating the resources. This is achieved in the model by altering the input-output relationship of each sector, i.e., by setting policy as to how the resource production is allocated to meet the requirements. A decision to change policies of resource allocation becomes, in the model, a change in the production equations themselves.

The System Model [Figure 2]

Each of the sector models can be used as a basis of limited analysis and planning directed at the specific sector to which it refers, or they can be combined as described next to establish a model of the entire system.

When the independent descriptions of the sectors are combined, constraints are imposed on the values that the related variables may assume. The credit hours produced by Academic Production are those demanded by the Student sector. The building space used in connection with Physical Facilities is equal to that needed to produce the classroom, laboratory, office, and other space demanded as shown pictorially in Figure 2. The use of personnel is similarly constrained. Such a model differs from traditional economic models in that all resources are considered as scarce, when compared to demands, and demands are regarded as obligations which must be met. The "inputs" of personnel and physical facilities are considered to be totally utilized in each time period and are therefore regarded as the resources required to meet production, under existing operating policies.

The most interesting and technically difficult constraints included in the total system description concerns the composition of the student body. The number of graduate assistants employed by the university is related to the undergraduate student enrollment distribution, through the demand for undergraduate course credit hours. On the other hand, the enrollment distribution, at least in the graduate levels, depends in part on the availability of graduate assistantships. Therefore, the equations of the model describe a circular relationship, or loop, associated with the employment of graduate assistants. Questions concerning allocation of resources and costs to various student programs can only be answered by descriptions which account for this circular relationship.

The model can be updated periodically in two ways to respond to changes in the institution. First of all, since the total system model is composed of models of separate sectors of activity, the theoretical model itself can be modified by addition, aggregation, or redefinition of its sectors and variables, within the overall mathematical model. Secondly, and more important, the numbers in the equations may be re-evaluated periodically from current data or according to changes in operating policies imposed by the administration.

ANALYSIS AND PLANNING PROGRAMS

Depending on the types of problems to be approached, a variety of analysis and planning programs may be developed, based on the theoretical model. Each program allows experimentation with particular types of variables and policies and yields particular information. Some decisions involve restricted sectors; others involve all areas of activity. Some are based on sector or system models in their given forms, and some are based on inverse relations derived from the models.

The analysis and planning programs depend also upon the approximations one is willing to make. For example, if the circular relationship between the student employment and student enrollment is neglected, separate computer simulation programs can be constructed for each of the several sectors, with the output of one simulation program serving as the input to the next. Thus, the model of the student sector could be used in any one of several ways to predict student enrollment. Knowing the student enrollment, the model of the production sectors could be used to determine the academic and non-academic services required to meet the student needs. Knowing the manpower and facilities input to the academic and non-academic sectors, the required resource inputs to the Personnel and Physical Facilities sectors could be determined. In a similar manner, the costs per unit of production at the various stages could be computed sequentially starting with the unit costs of the input resources and proceeding to the production outputs.

However, such approximations can lead to inconsistencies or unbalances. Indeed, the sequence of computations described above for a particular set of policies in the employment of graduate students in the academic program and research will show a need for a particular number of graduate students. These students may or may not be available in the student population as projected by the model of the student sector. This unbalance, of course, can be removed iteratively by first re-estimating the student population, taking into consideration the availability of assistantships and then re-evaluating the manpower requirements. This process must be repeated until the circular loop is balanced.

In theory, the model on which the programs are based can be particularized to any given university at any level of aggregation starting at the department level. However, machine storage requirements and computation time impose severe upper bounds on the level of disaggregation that can be implemented and how it is implemented in a computer program. If, for example, there are 12 colleges with 10 departments each if 4 levels of study are identified for each department, then the number of coefficients in the transition matrix in the model of the student sector is $(12 \times 10 \times 4)^2 = 230,400$. Although many of these entries are zero, the storage requirements are large indeed, to say nothing of the population levels in the 480 categories and the 480 student-credit-hours requirements that are generated as output by the program.

It is evident then that any given analysis and decision program based on the model must be addressed to a particular class of questions and must capitalize on aggregation in some manner or another. If information at the department or college level is required, then perhaps the program should be constructed so that one or two designatable departments appear in detail with all others aggregated into one category. The programs already constructed for evaluating the behavioral parameters in the model of the student sector from the files include this feature.

From the user's point of view, there are many additional questions that must be answered. Among them are: "What general level of technical understanding is required?" and "Must the user see the results of one experiment before he can effectively proceed to the next?" In the face of vast quantities of program input and output information, provision must be made whereby the user can specify what results he sees and what policy parameters he wishes to change without becoming involved in all the rest. Some output data he will desire in detail; other results may be more meaningful in summary form.

Finally there is the question as to how long the program must "live" and how amenable it should be to modification. Certainly changes are made from time-to-time in the structure of the institution. Also, the task of developing analysis and decision programs must be regarded as a continuous effort, starting with modest programs having quite limited capabilities, accumulating to ever-increasing capability and sophistication.

In an attempt to answer some of the many questions associated with implementing model-based analysis and planning programs as practical instruments in the hands of decision makers, a prototype of an allocation and budgeting program has been developed. This program is based on the complete model of the institution, taking into consideration the circular dependence between student enrollments and graduate assistantships. The class of questions it answers, the way in which they are answered, and the manner in which the user interacts with it are discussed in detail in the next section. The number of categories of students is purposely limited to two fields and two levels so that during the development period of the program it can be operated in a conversational mode on the GE-265 time-sharing system.

PROTOTYPE ALLOCATION AND BUDGETING PROGRAM

In a time-sharing computer system a teletypewriter is connected to a computer over regular telephone lines. The user establishes the connection by dialing a telephone number, then communicates with the computer program through the keyboard and printer of the teletypewriter, sharing computer time with any other consoles that are similarly connected. Response times are usually in the order of a few seconds plus the printing time, though with complex programs or many other users sharing times, this can be a matter of minutes.

The program carries out the mathematical computations called for in the mathematical model, using numerical values for all policy parameters and variables. It begins with a projection of next year's enrollment based on current policy and behavioral parameters and exogenous variables that have been previously stored in the program.

The user receives a printout of the following enrollment figures with a question as to what additional information he would like to see.

```
DEMONSTRATION
NO. OF NEW STU     1500
                               ENGINEERING             NON-ENGINEERING
                           UNDERGRAD      GRAD      UNDERGRAD       GRAD

ENROLLMENT THIS YEAR         305.          72.        3000.          484.
ENROLLMENT NEXT YEAR         305.          72.        3000.          484.
WANT MORE INFO?  (0=COST TOTALS ONLY, 1=ALL BUT RATES, 2=ALL,
3=NO MORE)? ?2
```

The number 2 appearing at the end of the above printout indicates that the user has asked for all additional information, to which the program responds with the following:

```
                                  ENGINEERING            NON-ENGINEERING
                               TEACH     RESEARCH     TEACH        RESEARCH

$/FTE GRAD ASSTSHIP            4400.       4800.       4400.        4800.
                                 6.          15.         66.          20.
                                  ENGINEERING            NON-ENGINEERING
                             UNDERGRAD       GRAD    UNDERGRAD        GRAD

$/FTE FACULTY MEMBER
   TO TEACH                   13000.      14000.      12000.       13000.
FTE FACULTY NEEDED
   TO TEACH                     17.         10.        136.          66.

$/SUPPORT FACILITY            3000.00

AMOUNT OF SUPPORT FACILITIES NEEDED       793.209

NO. OF OUTSIDE SERVICES     25.00

FAC AND GRAD ASST
   TEACHING BUDGET        244020.      144251.     1925803.      864373.
   RESEARCH BUDGET:    ENGIN       74175.00     NON-ENGIN    96000.00

TOTAL BUDGET--FACULTY, GRAD ASSIT., AND SUPPORT   5730235.20
```

The enrollment projections are based on the assumption that the decision of some students to attend (this) school is based on the availability of financial aid. The number of teaching assistantships offered by the university is based on the undergraduate enrollment, while the number of research assistantships is based on outside services (research contracts, for example). Thus the second line of the printout specifies the number of graduate assistants needed for these purposes. The first line represents the cost per FTE (full-time equivalent) assistantship. The cost and numbers of regular faculty required to operate the system appear in lines three and four. Lines five and six represent, respectively, the given cost per unit of support facilities and the number of units required to meet the system needs under the given policies of operation.

The outside service figure is entered into the program as a known quantity, with the view that it is determined, within limits, by the general policy of the university in promoting research, continuing education and other public services. Again, no attempt has been made in the present prototype program to include a definitive breakdown of these services.

Finally the budget items are summarized. So far the user has had an opportunity to view the projection for next year based on current policies and conditions. At this point he will, in general, wish to explore the consequences of changes in various policies and in certain exogenous variables. To inform him of what changes he can make and what their current values are, he is given the opportunity to call for the additional information in the following printout.

```
YOU MAY SEE:  ASS'TSHIP ATTRACTION TBL-1; SCHLRSHP ATTR TBL-2;
CLASS CRED TBL-3; RESEARCH CRED  TBL-4; STU TRANSITION TBL-5;
PERCENT BRKDWN OF NEW STU-6; CURRENT CREDIT DEMAND-7;
SCHOLARSHIPS-8;
NONE (NO MORE)-9?  ?1
     .0500       .0400     0.0000      0.0000
     .6600       .7600      .0500       .0400
    0.0000      0.0000      .0600       .0600
     .1200       .0900      .7500       .8000
? ?3
   33.0000      6.0000      .5000       .1000
    2.0000     21.0000      .0500       .1000
   10.0000      0.0000    42.0000      6.0000
    0.0000      9.0000     1.5000     20.0000
? ?5
STUDENT TRANSITION TAB LE
ENGIN UNGR                    .45000     0.00000     .00100     0.00000
ENGIN GRAD                    .02000      .30000     .00100      .02000
N-ENG UNGR                    .10000     0.00000     .60000     0.00000
N-ENG GRAD                    .01000      .09000     .05000      .40000
? ?6
       9.70         .50        75.50        6.50
? ?7
NO. OF CREDITS--CLASS
   12037.        2322.        131972        14837.
NO. OF CREDITS--RESEARCH
    .        409.        .        3806.
? ?8
NO. OF SCHOLARSHIPS, ETC.
   20.        10.        60.        18.
? ?9
```

The printout indicates that the user has responded six times to the initial question by calling for the categories of parameters and variables indicated by the code numbers 1, 3, 5, 6, 7, 8. Finally he says "NO MORE" with code 9.

The first table, entitled Assistantship Attraction table, shows the number of students attracted to a given field-level category by assistantships offered in each category. The assumption is that an assistantship may attract more than one student, since others may enroll with the expectation of getting such assistance at a later time. For example, an undergraduate who sees the graduate assistantships in the field of management may enroll as an undergraduate in anticipation of receiving a graduate assistantship when he becomes a graduate student. A similar table exists for Scholarships.

The Class Credit Table (code 3) shows the number of class credit hours taken by students in each category. Thus the engineering undergraduate, on the average, takes 33 credit hours of engineering undergraduate work, two credits of engineering graduate courses and 10 non-engineering undergraduate. If the Curriculum Committee were to specify that students are required to take more work in one department and fewer in another, then this change in academic policy would be reflected by a corresponding change in this table.

The Student Transition Table (code 5) describes the movement of students through the university. As used here, it actually represents those students who remain in the system regardless of financial aid. For example, 45% of the engineering undergraduates are still undergraduates the following year, while 2% move to the engineering graduate school, 10% to non-engineering at the undergraduate level and 1% to the non-engineering graduate level. The remaining 42% either graduate or would fail to re-enroll in the absence of financial aid. The influence of financial aid on enrollment is determined by the Attraction Tables, the Scholarships available (described below), and the Assistantships required (explained above). It is assumed that enough students are available either from within the system or as new students to meet these needs. It is possible, of course, to bound the variables in the program to reflect a limited supply of graduate students.

The table on the Percentage Breakdown of New Students (code 6) represents, in part, the student's choice of field as he enters at the various levels. They also reflect, to some extent, administrative policy on admission, such as fixed upper bounds or admittance to certain profession schools and limited out-of-state admissions.

Current Credit Demand (code 7) gives the credit hours required during the term. These figures are actually controlled by the user through the other parameters, primarily the Class Credit Table.

Finally, the user is informed, by the last table, of the number of scholarships currently offered. These, of course, influence enrollment and operational costs but differ from assistantships in that the university derives no manpower benefits from them.

Having seen the results from one year and having been advised of current policies, the experimenter may now change certain parameters to evaluate their effect on the system. The program reminds him of this opportunity and gives him the option to see the "key for changes."

```
ANY CHANGES FOR YEAR      2?  (0=NO, 1=YES)? ?1

WANT KEY FOR CHANGES?     (0=NO, 1=YES)? ?1
(NO OF NEW STU-1; OUTSD SERV-2; $/SPPRT FACIL-3; ENROLMNT-4;
PERCENT BRKDWN OF NEW STU-5; $/FAC MEM-6; $/GRAD ASST. -7;
SCHLRSHPS-8; TRANS TBL-9; CLASS CRED TBL-10; RESEARCH CRED
TBL-11;
BACK TO YEAR 0 (INITIAL DATA) - 12; NO MORE CHANGES-13)
```

Eleven different sets of parameters may be changed and the initial data can always be retrieved so that comparisons can be made of alternative policies using a common basis.

As one experiment, suppose the question to be answered is: "What is the effect of doubling the number of engineering graduate scholarships?"

The class of parameters to be changed is identified as (code 8) with a subsequent change in the scholarships to (20, 20, 60, 18). Since no additional changes are to be made, the above instructions are followed by (code 13).

```
? ?8
PLEASE TYPE IN THE ENTRIES AFTER '?'
? ?20, 20, 60, 18
MORE CHANGES ? ?13
WANT TO SEE RESULTS FOR YEAR 2?  (0=NO, 1=YES)
? ?1
```

As the printout indicates, the user now has the option of seeing the projection for year 2. In some experiments, he may want to see only the ultimate or "steady-state" consequences of the change, omitting the intermediate printout. Code 1 indicates that the user has elected to see the results for year 2.

They are

```
NO. OF NEW STU      1500

                                ENGINEERING            NON-ENGINEERING
                            UNDERGRAD    GRAD      UNDERGRAD       GRAD
ENROLLMENT THIS YEAR           305.       72.        3000.          484.
ENROLLMENT NEXT YEAR           305.       80.        3000.          484.
WANT MORE INFO?       (0=COST TOTALS ONLY= 1=ALL BUT RATES,  2=ALL,
   3=NO MORE)?  ?1
```

The printout indicates that the change (10 more scholarships) has resulted in 8 more engineering graduate students. The user now has the option of calling for the various classes of additional information indicated in the last line of printout. Since rates (faculty, assistantship cost, etc.) were not changed, time is saved by calling for the class of information identified by code 1. This response is

```
                        ENGINEERING           NON-ENGINEERING
                     TEACH      RESEARCH     TEACH      RESEARCH
FTE ASSTSHIPS NEEDED  6.          15.         66.          20.
                        ENGINEERING           NON-ENGINEERING
                     UNDERGRAD    GRAD      UNDERGRAD      GRAD
FTE FACULTY NEEDED
   TO TEACH                 17.        11.        136.         67.

AMOUNT OF SUPPORT FACILITIES NEEDED      794.069

NO. OF OUTSIDE SERVICES      25.00

FAC AND GRAD ASST
   TEACHING BUDGET        244687.    152156.    1925803.    865215.
   RESEARCH BUDGET:  ENGIN          74175.00   NON-ENGIN   96000.00

TOTAL BUDGET--FACULTY, GRAD ASST., AND SUPPORT  5742229.80
```

Note that two additional faculty members are now required, one each in engineering and non-engineering.

For comparison suppose 10 new scholarships are provided beginning with year 3 in the non-engineering undergraduate category as indicated by the following printout.

```
ANY CHANGES FOR YEAR      3?  (0=NO, 1=YES)? ?1
WANT KEY FOR CHANGES?    (0=NO, 1=YES)? ?0
? ?8
PLEASE TYPE IN THE ENTRIES AFTER '?'
? ?20, 20, 70, 18
MORE CHANGES? ?13
WANT TO SEE RESULTS FOR YEAR 3?  (0=NO, 1=YES)
? ?1
NO. OF NEW STU        1500
```

```
                            ENGINEERING          NON-ENGINEERING
                        UNDERGRAD   GRAD     UNDERGRAD      GRAD
ENROLLMENT THIS YEAR      305.       80.      3000.          484.
ENROLLMENT NEXT YEAR      305.       83.      3006.          485.
WANT MORE INFO?   (0=COST TOTALS ONLY, 1=ALL BUT RATES, 2=ALL,
3=NO MORE)? ?1
```

The results above show an increase of 6 undergraduate non-engineering students in the first year following the change,while below the steady-state results of such a policy indicate an ultimate enrollment of (408, 110, 3040, 495), an increase of (102, 26, 25, 8). The policy change definitely has long-range effects.

```
ANY CHANGES FOR YEAR       9?   (0=NO, 1=YES)? ?1

WANT KEY FOR CHANGES?    (0=NO, 1=YES)? ?0
? ?8
PLEASE TYPE IN THE ENTRIES AFTER '?'
? ?100, 20, 70, 18
ANY CHANGES FOR 16?  (0=NO, 1=YES)? ?0
WANT TO SEE RESULTS FOR YEAR 16?  (0=NO, 1=YES)
? ?1
NO. OF NEW STU      1500
                             ENGINEERING          NON-ENGINEERING
                         UNDERGRAD GRAD       UNDERGRAD    GRAD
ENROLLMENT THIS YEAR       408.       110.       3039.        494.
ENROLLMENT NEXT YEAR       408.       110.       3040.        495.
WANT MORE INFO?    (0=COST TOTALS ONLY, 1=ALL BUT RATES,
2=ALL, 3=NO    MORE)? ?2

                             ENGINEERING          NON-ENGINEERING
                          TEACH   RESEARCH       TEACH    RESEARCH
$/FTE GRAD ASSTSHIP       4400.     4800.        4400.     4800.
FTE ASSTSHIPS NEEDED         8.       15.          67.       20.
```

```
                                   ENGINEERING    NON-ENGINEERING
                              UNDERGRAD   GRAD   UNDERGRAD   GRAD

$/FTE FACULTY MEMBER
   TO TEACH                    13000.    14000.    12000.    13000.
FTE FACULTY NEEDED
   TO TEACH                      20.       13.       139.       68.

$/SUPPORT FACILITY   3000.00

AMOUNT OF SUPPORT FACILITIES NEEDED   825.6996

NO. OF OUTSIDE SERVICES   25.00

FAC AND GRAD ASST
                         TEACHING BUDGET    294721.   184369.   1962153
   RESEARCH BUDGET:  ENGIN    74175.00    NON-ENGIN     96000.00

TOTAL BUDGET--FACULTY, GRAD ASST., AND SUPPORT      5973511.20
```

CONCLUSIONS

The state-space model of an educational institution described in this paper can be used as the basis for a wide variety of computer programs to aid in planning and resource allocation. If these programs are to be effective tools in the hands of administrators,they must be designed to meet <u>his</u> needs---they must answer questions that are meaningful in the context of the decisions he makes and answer them in convenient and useful format.

The prototype program presented in this paper was designed to serve as a vehicle of communication between operations analysts and administrators in arriving at effective program designs. To this end it is purposely aggregated to a level that can be implemented on time-sharing equipment in a conversational mode. Even so, worthwhile results can be derived from this relatively simple version when the coefficients represent a realistic situation,and the above illustrations should indicate the usefulness of simulation programs.

Administrators, experimenting with the prototype program, can discover more clearly the features that an effective program should have. In this sense, the given prototype does not represent an "optimal" or most useful design---it only represents the first expression of the systems analyst to communicate to the administrators what might be made available.

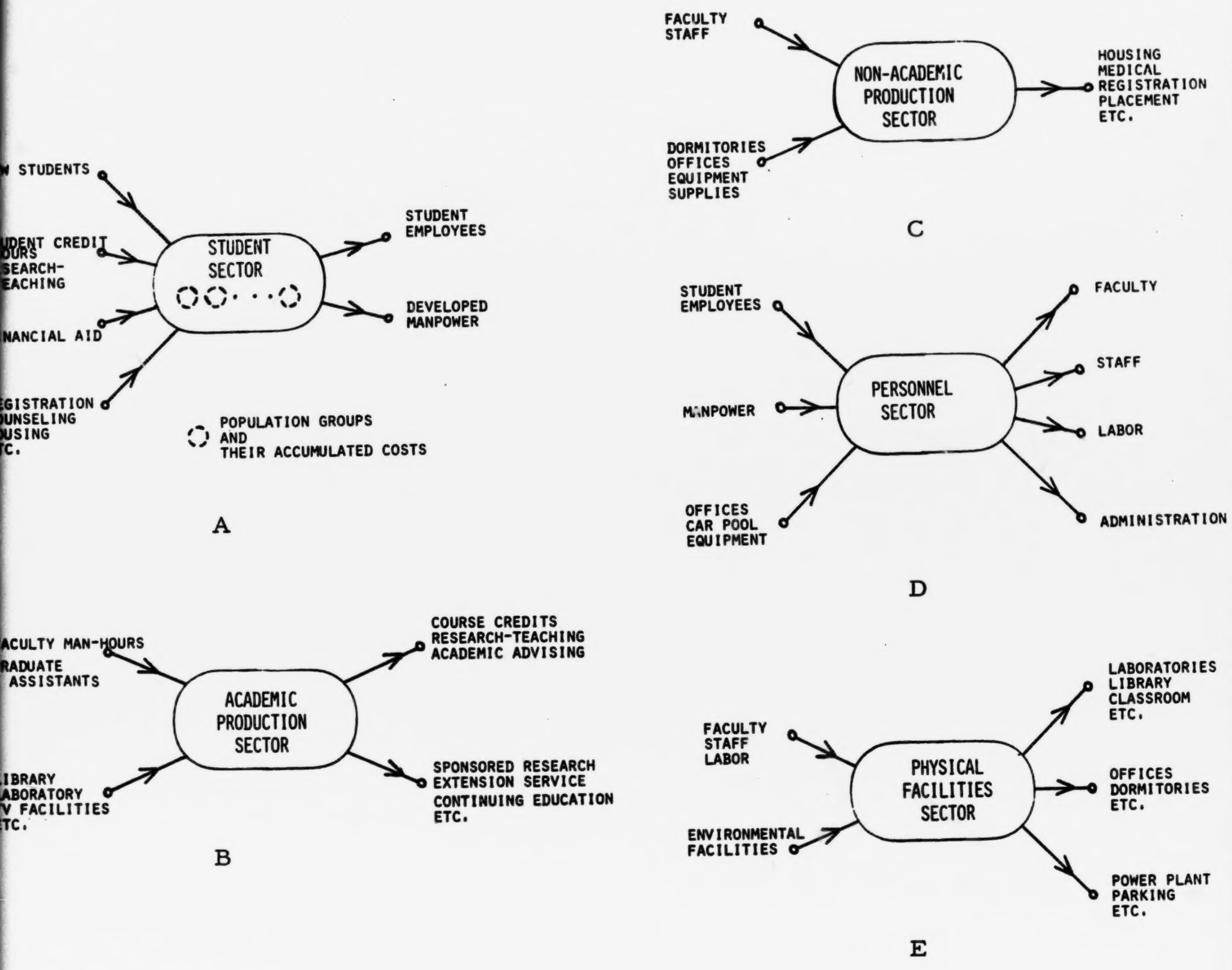
FACULTY
STAFF
NON-ACADEMIC
PRODUCTION
SECTOR
HOUSING
MEDICAL
REGISTRATION
PLACEMENT
ETC.
DORMITORIES
OFFICES
EQUIPMENT
SUPPLIES
C
W STUDENTS
UDENT CREDIT
OURS
SEARCH-
EACHING
STUDENT
SECTOR
STUDENT
EMPLOYEES
DEVELOPED
MANPOWER
NANCIAL AID
EGISTRATION
UNSELING
USING
TC.
POPULATION GROUPS
AND
THEIR ACCUMULATED COSTS
A
STUDENT
EMPLOYEES
PERSONNEL
SECTOR
FACULTY
STAFF
LABOR
MANPOWER
OFFICES
CAR POOL
EQUIPMENT
ADMINISTRATION
D
ACULTY MAN-HOURS
RADUATE
ASSISTANTS
ACADEMIC
PRODUCTION
SECTOR
COURSE CREDITS
RESEARCH-TEACHING
ACADEMIC ADVISING
IBRARY
ABORATORY
V FACILITIES
TC.
SPONSORED RESEARCH
EXTENSION SERVICE
CONTINUING EDUCATION
ETC.
B
FACULTY
STAFF
LABOR
PHYSICAL
FACILITIES
SECTOR
LABORATORIES
LIBRARY
CLASSROOM
ETC.
OFFICES
DORMITORIES
ETC.
ENVIRONMENTAL
FACILITIES
POWER PLANT
PARKING
ETC.
E

Figure 1. Basic Sectors of the Model.

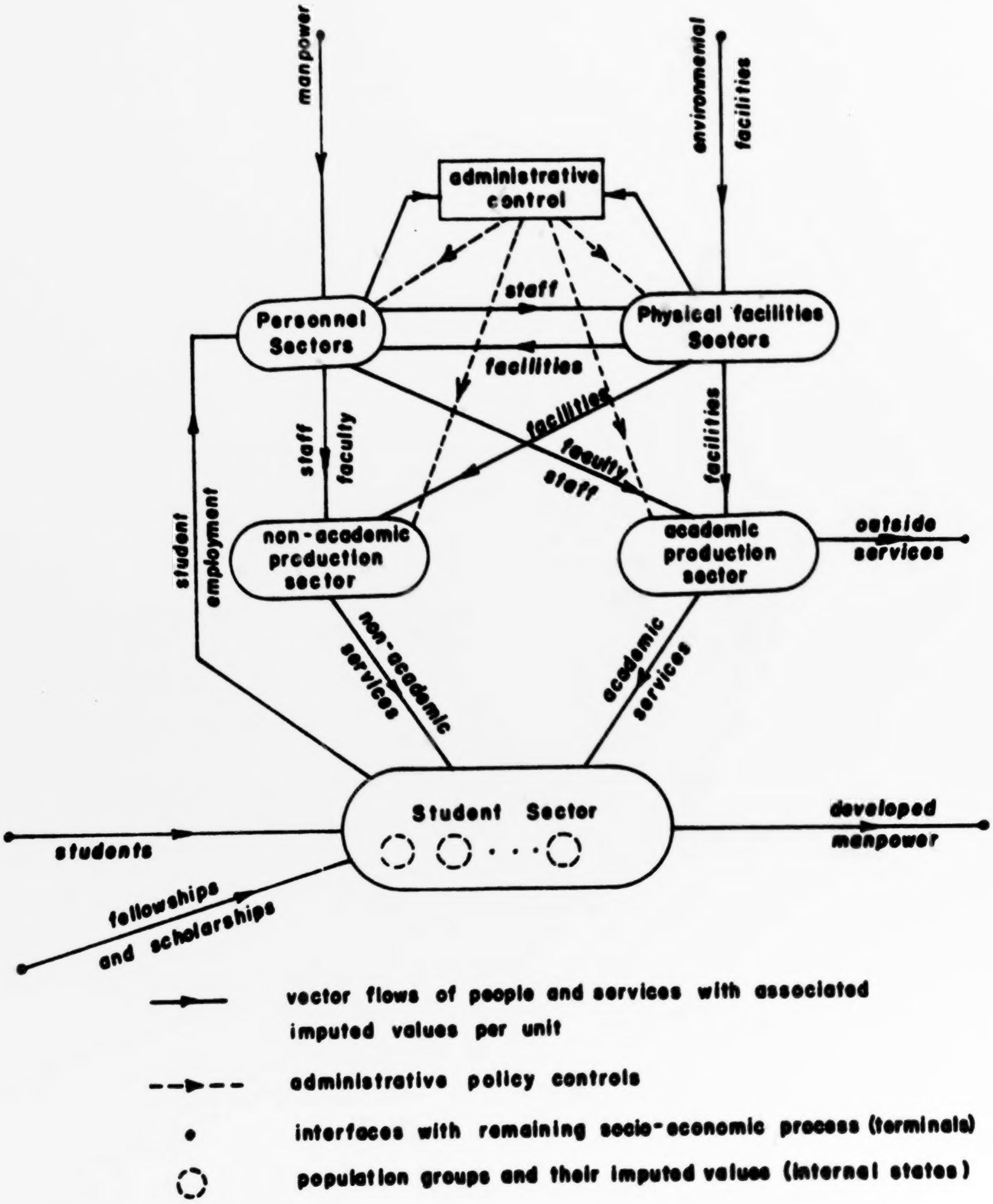
manpower
environmental
facilities
administrative control
staff
Personnel Sectors
Physical facilities Sectors
facilities
staff
faculty
facilities
faculty
staff
facilities
student employment
non-academic production sector
academic production sector
outside services
non-academic services
academic services
Student Sector
students
developed manpower
fellowships and scholarships
vector flows of people and services with associated imputed values per unit
administrative policy controls
interfaces with remaining socio-economic process (terminals)
population groups and their imputed values (internal states)

Figure 2. Structure of the System Model

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(3) Zemach, "A State-Space Model for Resource Allocation in Higher Education," Technical Report, Division of Engineering Research, Michigan State University, 1967.

(4) Keeney, M. G., Koenig, H. E., and Zemach, R., "A Systems Approach to Higher Education," Final Report, Project C-396, National Science Foundation, Washington, D. C., Division of Engineering Research, Michigan State University, 1967.